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Flat Panel Displays in an Automotive Environment

by

Anthony Slack

for

A Master of Philosophy Degree

**The Open University
Milton Keynes**

April, 1997

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Abstract

A study was made of the field of flat panel displays, and their potential application in an automotive environment. Using contemporary display technology, semiconductors and software, a model was developed to fit an existing automotive instrumentation application. The resulting model was critically assessed in respect to the demands of such an application in respect to existing instrumentation methods. The viability and suitability of implementing such a design are discussed as well as its ability to be intrinsically portable and adaptable.

Acknowledgment

As is customary on these occasions, and indeed necessary in this particular case, I must take time out to thank those without whose effort this work would never have been completed. Firstly, through stormy weather and continental shifts, my partner Yvonne, whose willingness to take on more than her fair share of life's chores and odd jobs, gave me time to groan and at times study. Also for her enthusiastic, and energetic support. To my family and friends for their ridicule when I was lacking motivation. Roy Collins of Lucas Body Electronics, for supplying the Jaguar pack and years of wisdom and expertise. Also Ian Coward of Stanley Idess, for the help in sourcing both LCD and LED. Ron Clarke of Mhotrak Ltd., who fabricated my Printed Circuit boards for me. Saving me hours labouring over a dirty etching tank. Andrew Goodings for his invaluable help in providing the software to operate the final model. Finally, to my two tutors. Dr. Richard Aldridge of the UEA, for constantly correcting my direction, and lighting a few timely rockets. Then Dr. Nicholas Braithwaite of the Open University, who, despite my attempts to abscond to Hong Kong, has very long arms and has kept me on track. Both of these people in particular I must thank sincerely, though at times I found the extent of their knowledge and expertise particularly un-nerving. I only hope they didn't find me out!

Glossary of Terms

ACTFEL	- AC Thin Film EL
AMLCD	- Active Matrix LCD
CCFL	- Cold Cathode Fluorescent Lamp
CRT	- Cathode Ray Tube
DCEL	- DC Electroluminescent
DCPEL	- DC Powder EL
DS	- Dynamic Scattering
DSTN	- Double Layer STN
EL	- Electroluminescent
EMC	- Electromagnetic Compatibility
EPOS	- Electronic Point Of Sale
EPROM	- Erasable Programmable Read Only Memory
ETN	- Enhanced TN
FED	- Field Emission Display
FLCD	- Ferroelectric LCD
FPD	- Flat Panel Display
FPED	- Flat Panel Electronic Display
FSTN	- Film Compensated STN
GPS	- Global Positioning Satellite
HCFL	- Hot Cathode Fluorescent Lamp
HDTV	- High Definition TV
HEX	- Abbreviation of Hexadecimal
HTN	- Hyper TN
HUD	- Head Up Display
IC	- Integrated Circuit
ISO	- International Standards Organisation
ITO	- Indium Tin Oxide
LC	- Liquid Crystal
LCD	- Liquid Crystal Display
LED	- Light Emitting Diode
MTN	- Modulated TN
PC	- Personal Computer
PCB	- Printed Circuit Board
PDP	- Plasma Discharge Panel
PMLCD	- Passive Matrix LCD
RAM	- Random Access Memory
RGB	- Red, Green, Blue
SMT	- Surface Mount Technology
STN	- Super Twisted Nematic
TFT	- Thin Film Transistor
TN	- Twisted Nematic
UV	- Ultraviolet
VCR	- Video Cassette Recorder
VDU	- Visual Display Unit
VFD	- Vacuum Fluorescent Display
VGA	- Video Graphics Adapter
Vled	- LCD drive voltage

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1.0 Introduction

Information technology is at the forefront in the revolution of modern society, with overwhelming volumes and variety of information circulating on vast global networks of communication. Electronic displays are the most effective means of interfacing with this medium. Consider, for example, a computer terminal, where information is required in an immediately clear, concise and ordered fashion, at relatively close proximity, and easily updated upon request. Whilst outwardly similar to, say, a television monitor, intrinsically differing demands on resolution, brightness and aspect ratio exist. This is due to the differences in typical viewing conditions and in the nature of information presented, though both still usually operate within a restricted and well defined range of environmental conditions.

Perhaps a more perplexing example to consider would be the cockpit of an aircraft where such a comfortable environmental operating range may not be so easily defined. Here a wide variety of information must be available to the pilot without demanding prolonged interrogation. In this type of application, where differing functional demands are required of individual instruments, the operating criteria can be found to be less well defined. Extreme environmental conditions, such as harsh incident light, wide variance in operating temperature and vibration exist, together with statutory safety requirements regarding, for example, colour co-ordination. It is easy to imagine how confusing such an arrangement could become without careful planning by the instrumentation engineer and the strict specification of each component. It is only too apparent what consequences arise from any misinterpretation of information. In addition, there are further considerations such as mechanical bulk and weight to be reconciled. Historically all such information would have been provided by mechanical and electro-mechanical means, often referred to as analogue, such as we are still accustomed to seeing in contemporary automotive dashboards. Though they are relatively cheap, reliable and robust they have the disadvantage of only being able each to perform a single function. The consequence is a confusing plethora of dials and gauges.

Whilst perhaps an extreme example, the aviation application illustrates many of the problems endemic to instrumentation engineering. A more pertinent example may indeed be a modern automobile. Here, although the breadth of information demanded may be less critical, and the environmental aspects less rigorous than the previous example, matters are further compromised by the demands of the stylist, the marketer, economics and the most divergent of all, the consumer. The human half of such a "man/machine interface" is rarely more than a semi-skilled operative.

Once again many of the functions present have been, and in the vast majority of cases still are, performed by traditional mechanical and electro-mechanical devices. Indeed, in many cases such devices have been found to be less demanding on the operator than electro-optical arrangements, though undoubtedly familiarity plays a significant part. However, the burgeoning number of ancillary instruments is becoming confusing and increasingly difficult to package, requiring increasingly complex assemblies. This also affects both the reliability and cost effectiveness of the finished product. An ideal solution would be to remove all ancillary and non-essential information, integrating each function into a single instrument that could be quickly reconfigured to present specific information upon request.

It is difficult to see how a device of this nature could be achieved within the limitations of traditional mechanical, and electro-mechanical instruments. Whilst the task would be made easier if electronic display components were incorporated, what is required is a device whose format can be rapidly reconfigured. An electro-optical device represents the most effective solution. By far the most common form of device which fulfils these demands is the ubiquitous cathode ray tube (CRT). Used in anything from computer terminals and TV sets, to aircraft instruments, the CRT, is the most mature of all available technologies and is still seen as the benchmark by which all others are compared. "Flat panel displays are on everyone's mind, but CRTs are on everyone's desk", was the de facto address of keynote speakers in the early 1990's. A CRT is relatively inexpensive, robust and has excellent operating characteristics. Unfortunately, there are several drawbacks to using this technology in an automotive environment. Power consumption, weight, mechanical bulk and the high levels of harmful radiation emitted are the major drawbacks. In the past the CRT had been the only practical alternative to the mechanical, and electro-mechanical devices previously mentioned for instrumentation. However, the relatively recent advent of portable computers, TVs and other battery operated equipment has resulted in the rapid development of a wide range of cheaper flat panel displays with excellent performance characteristics.

The purpose of this course of research was to investigate thoroughly the area of electronic flat panel displays, and research their application into solving contemporary instrumentation problems, choosing a single particular subject on which to develop a body of original research. The aim of this research is the design, development and manufacture of an alternative automotive instrumentation unit employing flat panel display technology and solid state light sources. In order to establish the validity of the development work it has been necessary to become fully conversant with both the operating principles and properties of the various available technologies, and the operating conditions demanded

in an automotive environment. This knowledge has been essential in predicting which direction current and future development lay. Early work in support of the general topic therefore concentrated heavily on a literature research of flat panel display technology. This is described in detail in the following chapter. The next chapter describes the general problems specific to information display within the automotive domain.

Adopting a top down approach a general specification was formulated for the unit. The various technologies described in the second chapter are then examined to assess the suitability of each, before justifying the selection of a particular technique on which to base the development of the final product. All aspects of the design, development and implementation of the solution are discussed in chapter 4. Chapter 5 presents a discussion of the findings accumulated as a result of testing and subsequent referral to an established automotive manufacturer. The thesis concludes by highlighting areas of future development, possible future techniques, and developments which would be required in order to solve the remaining problems.

2.0 Flat Panel Electronic Displays, an Overview

An explanation of the rationale behind a thorough research of the field of Flat Panel Electronic Displays (FPED) has been suggested in chapter 1. It has been a fundamental pre-requisite of the design study that a broad understanding of the subject was gained in order for the final study to be relevant and validⁱ. However, the subsequent design study should be recognised as having developed the overall knowledge and expertise in the broader field of displays, as opposed to the reverse. This chapter details basic display technology.

2.1 Liquid Crystal Displays (LCDs)

Of any of the technologies covered here the LCD is the most diverse, both in terms of application and basis of operation. In order to appreciate this diversity it is appropriate to have an understanding of exactly what constitutes a liquid crystal, and the many varied forms which it can take. Although it was not the purpose of this study to discuss the detailed science of liquid crystals a broad explanation of their nature is given here. For a thorough understanding of this field reference should be made to some of the standards works covering liquid crystal materials and their application in the field of electronic displays^{ii iii}.

A liquid crystal is a material which exhibits both the fluidity associated with a liquid and the ordered crystallinity associated with a solid. This state only persists within a limited temperature range. As the temperature of the material tends toward the upper limit, so the properties tend increasingly toward that of a true liquid, to the point where the material undergoes a phase change and becomes truly liquid. This limit is called the 'clearing point' of a liquid crystal. Similarly, as the temperature tends toward the lower limit the properties tend toward those of a true solid. These materials are known as mesogens, and such a phase state in a material is known as a 'mesophase'. Fig. (1) shows the molecular diagram for such a material with an illustration of its simplified phase diagram. This phase is formed when a molecule is created having rod-like characteristics with a length-width ratio in excess of 3:1, containing polar groups which provide the intermolecular forces required to orient them. It is another peculiar feature that most such molecules used in electronic displays exhibit some degree of flexibility at the ends.

There are, generally speaking, three classes of liquid crystal material. These are nematic, cholesteric (chiral nematic) and smectic^{iv}. Of these nematic materials presently form the basis for the majority of display applications using liquid crystals. These materials are usually accompanied by lesser levels of chiral nematic materials. Such a relationship will be given greater detail in the

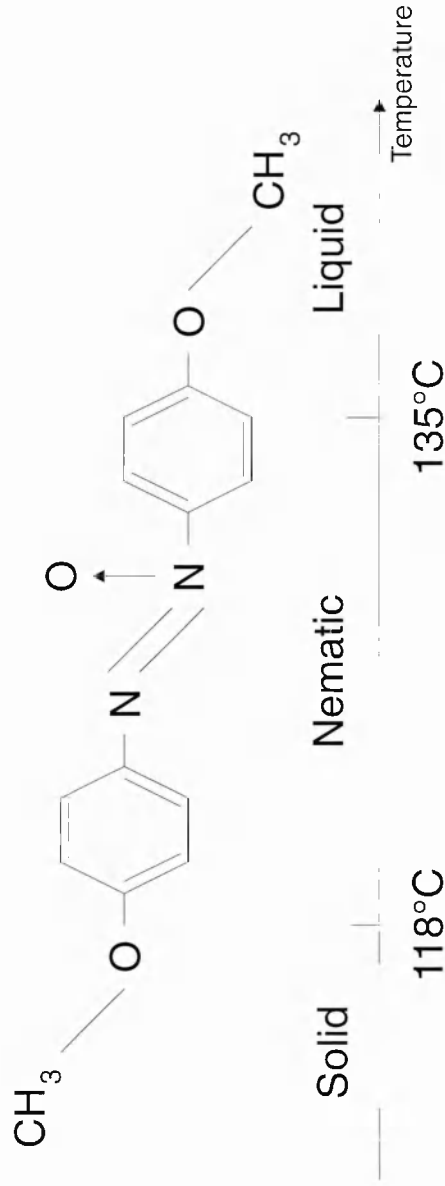


Fig. (1) Simplified Phase Diagram & Molecular Structure of PAA*

* *p*-azoxyanisole (*Hydrogen atoms have been omitted for simplicity*). This simplified diagram shows the transition points of this material from solid to nematic liquid crystal phase and on to liquid phase. Some liquid crystal materials show other intermediate phases, such as a smectic phase.

following pages. 'Nematic' is derived from the Greek word meaning "thread like", a reference to the molecular characteristics of such materials. The field of liquid crystal research is closely associated with the development of polymers.

The molecules in a nematic material are ordered into homogeneous layers in one dimension only, being randomly ordered in the other two dimensions. These homogeneous layers form parallel to the long axis of the molecules. This order is, however, relative. It can be shown that the number of molecules exactly aligned along a common axis within a liquid crystal is small. The relevant order is realised if one takes an average of the sum of the director, n (see Fig. 2) for each molecule. For an isotropic liquid no specific average alignment can be found. Anisotropy is found in liquid crystals because a bulk average alignment is present.

Cholesteric, or chiral nematic liquid crystals exhibit a similar degree of order to nematic materials. In this case though each homogenous layer is found to lie at some angle, in the same plane, to the adjacent layers, forming a helical structure. The term cholesteric is associated with the early work carried on liquid crystals derived from cholesterol. Chiral means twisted. This will be seen to be a key characteristic in the development of LCDs.

Smectic comes from the Greek word meaning "soap-like". Indeed the residue found around a bar of wet soap is a form of smectic liquid crystal. It is formed as a consequence of the hydrophobic nature of part of the molecule, and the hydrophilic nature of other parts of the same molecule. These materials exhibit orientational order similar to that of the nematics, but also have similar amounts of positional order. Some materials have both nematic and smectic phases over narrow temperature bands. Fig. (2) shows the relationship of the three basic classes.

2.1.1 Guest-Host Displays

The basis of using liquid crystal materials in display applications relies on the fact that the structure of the mesophase can be altered by the application of an electric field. In general small amounts of chiral nematic compounds are used for introducing helical twist to twisted-nematic, or super twisted-nematic LCDs (see later), as opposed to being used intrinsically for LCDs themselves. In the past they had been used extensively for 'Guest-Host' technologies, such as the Heilmeyer, and White-Taylor cell designs. In these cases the LC is used purely as the machine to control the orientation of dichroic molecules, typically. Such designs offer a wide range of different cell colour, though this is non-selective. However, their performance is limited due to poor response speed and contrast, although they do exhibit superior performance over wide viewing angles compared to traditional TN displays. Another drawback being the lifetime deficiency of the dye molecules, which

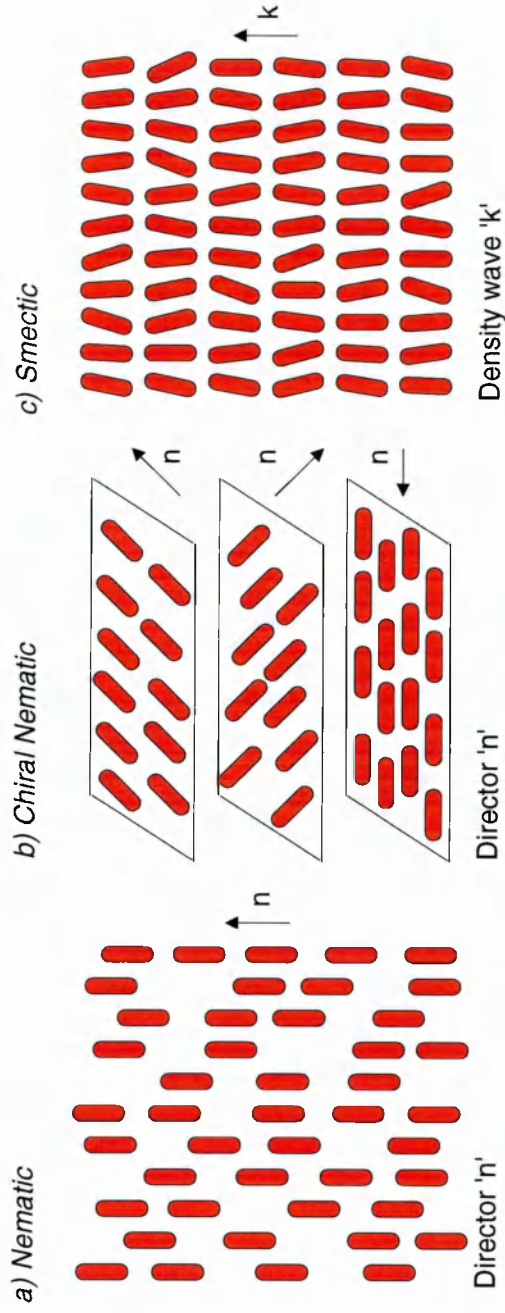


Fig. (2) Classes of Liquid Crystals
 Showing: (a) Nematic; (b) Chiral Nematic; (c) Smectic
 class material structures

are susceptible to UV radiation. They are subject to greater levels of attention at the moment as the level of research into polymer liquid crystals is increasing, especially in combination with active matrix addressing, of which more will be said later, which has enabled progress to be made in the area of response speeds.

2.1.2 Twisted-Nematic Displays

The greatest number of LCDs employ a technique known as twisted nematic (TN), or a generic development known as super twisted nematic (STN). The TN technique sandwiches the liquid crystal material between glass plates which have transparent electrodes, usually of indium tin oxide (ITO), formed across the inner surfaces. Additionally, each inner surface is coated with a polyimide material which is rubbed, or brushed in a particular direction. This induces the liquid crystal molecules to align themselves to the direction in which the polyimide has been rubbed. The directions of this rubbing on each plate are then arranged at some nominal angle relative to each other, typically 90° . The intrinsic nematic LC is doped by a small amount of chiral-nematic LC. This has the effect of inducing a natural twist in the molecular structure of the material and avoids problems of the nematic molecules twisting in different directions over the area of the display. This would cause the display to exhibit different levels of contrast between the differing areas of twist. The technique depends on the viewing angle relative to the normal axis of the molecules. This sandwich is placed between crossed polarisers, see Fig. (3). This has the effect of modulating the plane of polarisation of the light, effectively twisting the plane of polarisation by the induced angle of twist present in the LC. Traditionally that is 90° . Many commercial products use only 50° of twist. If an electric field is then applied perpendicular to the cell the molecules align parallel to the electric field. Reference should be made to the distribution of charge along the molecules and dielectric permittivity of the LC material to fully appreciate this phenomenon. Polarised light entering through the first polariser is, therefore, no longer modulated in such a manner as to allow it to pass through the second polariser, or analyser. The cell thus appears dark. The region over which this occurs is dictated by the areas over which the two sets of transparent electrodes overlap. So it may be seen that by careful arrangement of these electrodes the complex patterns we are familiar with are possible. Because of the nature of this mechanism LCDs are viewing angle dependent. As already stated the angle at which the display exhibits the maximum contrast is directly related to the angle of view relative to the average position of the nematic molecules. For this reason LCDs are typically classed by their optimum angle of view. That is 6:00 o'clock, 12:00 o'clock, etc., where 6:00 o'clock LCDs are optimised for viewing at an angle below the normal, for example.

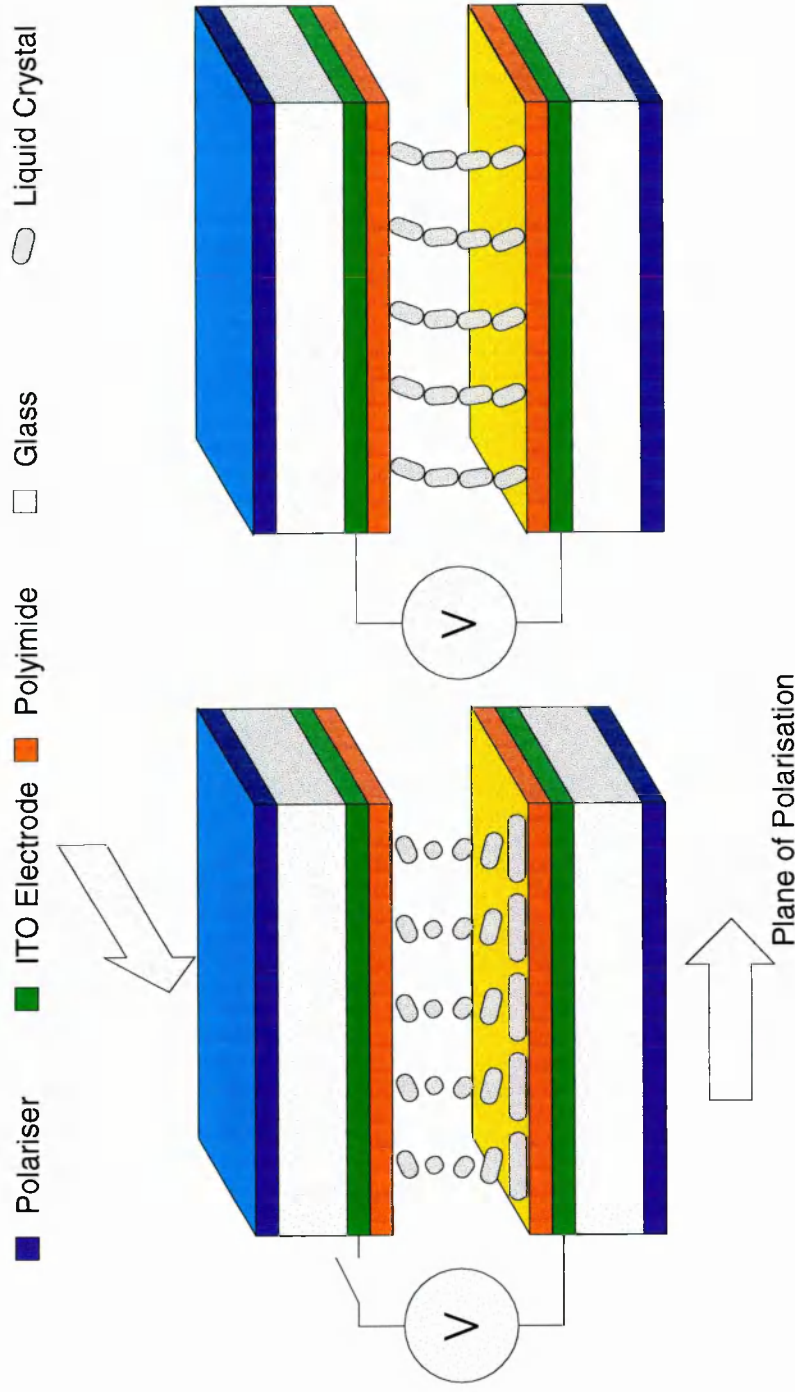


Fig. (3) TN Cell Construction & Operation

This figure shows the basic construction of a TN LCD cell and the principle of operation based on the application of an electric field. Note that in practice an alternating field is used with minimal DC content to avoid chemical degradation of the liquid crystal.

This arrangement works well enough whilst considering static, or low level multiplex, addressing schemes. If, however, the level of multiplexing is increased, so that the period during which the display elements are addressed is reduced, then the liquid crystal cells have less time to complete the full range of movement. This leads to a noticeable loss of contrast. To some degree this effect can be countered by reducing the rotational viscosity of the fluid. However, this in turn leads to a loss of contrast because the molecules of the liquid crystal relax to their natural order much more quickly. This inhibition is compounded by other factors. The threshold of liquid crystal materials, or the value of the corresponding electric field required to overcome the polar orientation of the LC molecules, does not exhibit a sharp transition. This transition is both time and voltage dependent, Fig. (4). Secondly, in order to avoid problems of chemical degradation of the liquid crystal materials due to electrolysis, LCDs must be driven by a symmetrical AC waveform. This can lead to noticeable 'crosstalk', where adjacent elements are affected by the addressing potential of neighbouring elements, leading to a loss of contrast. For these reasons simple TN displays are limited in the level of useful resolution that can be achieved.

2.1.3 Super Twisted-Nematic Displays

In the mid 1980's a technique was developed which resolved many of these problems. This became known as super twisted nematic (STN)⁹. Commonly the molecules within a STN LCD are twisted through a much greater angle than those of TN displays, typically 180° to 270° (though 240° is typical of today's technology). This method differs fundamentally from that of TN, relying on the mechanism of birefringence of the molecules rather than the modulation of the plane of polarisation of the light. Birefringence refers to the properties of the LC molecule which makes them exhibit differing indices of refraction in the X and Y planes. The greater range of movement required of the molecules within an active element increases the level of contrast. This rise in contrast gives rise to the useful levels of resolution possible through increased levels of multiplexing. To disorientate the increased level of molecular movement over much shorter addressing periods requires increased levels of voltage to address each element. It should be noted that traditionally this increase in the complexity of the cell has meant that STN has been stable over a much more restrictive temperature range. This has been largely redressed by improvements in the LC materials recently, and more often than not it is now the reliability of the materials used in the construction of the cells, such as the epoxies, that limit the use of either STN, or TN over extended temperature ranges.

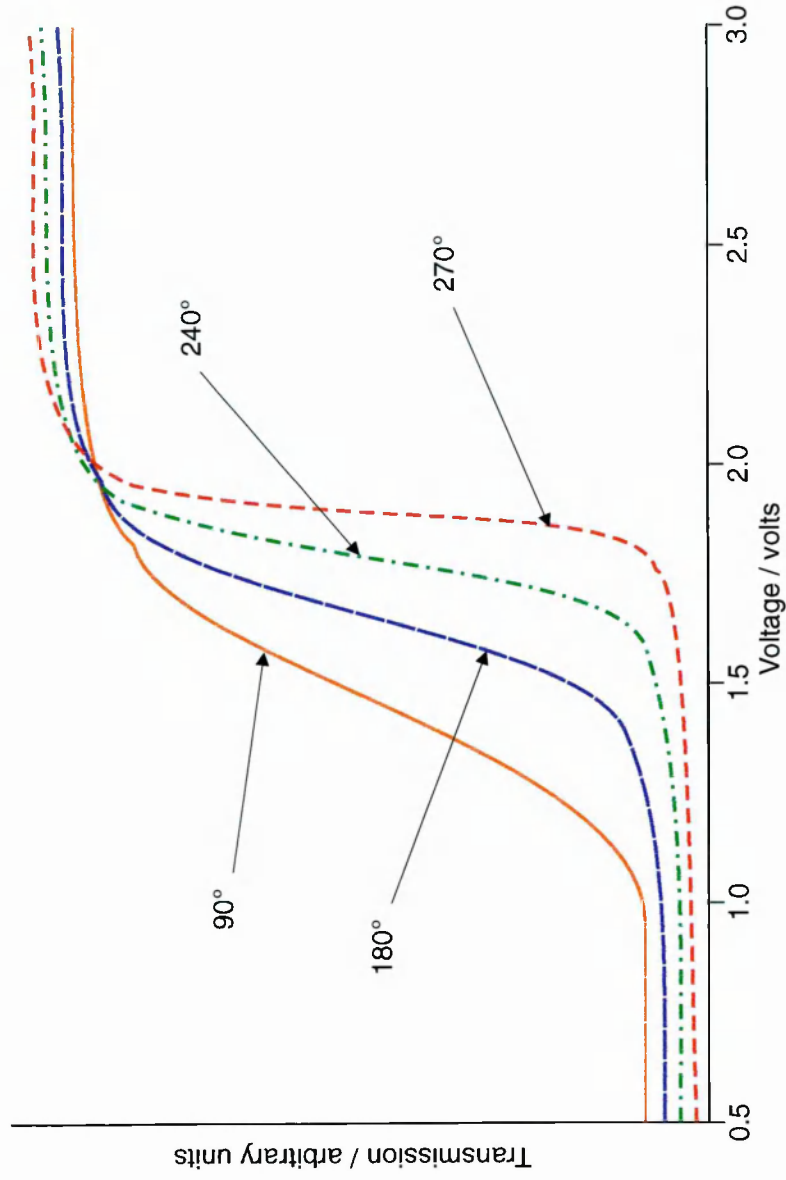


Fig. (4) Electro-optic response of LCDs

Representative results for a group of liquid crystal materials. 270° is considered the optimum level of twist. Beyond this the electro-optic response becomes an exaggerated 'S' curve.

2.1.4 Ferro-Electric Displays

Until relatively recently smectic liquid crystal materials had not been used for display purposes, the high viscosity of the material in the smectic phase being difficult to control. Serious research is now being carried out into their use though precisely because of the singular effect of this viscosity: bistability. When the molecular orientation in a smectic material is altered the viscosity of the material ensures that this change of orientation is retained indefinitely. The polar forces amongst the molecules in this phase are insufficient to overcome the frictional forces binding the molecules in place. Constant addressing schemes are no longer required to refresh the state of each active element. Relaxation of the molecules into some pre-active state does not lead to a loss of contrast, though, of course, each picture element now needs to be addressed to achieve both 'on' and 'off' states.

There are several classes of smectic materials. These are classed as 'A', 'B' and 'C', etc., referring to the various states of positional order which may be found in such materials. Of these only classes 'A' and 'C' have been used to implement a display. It has been mentioned earlier that such materials exhibit orientational order, similar to nematic and chiral nematic materials, and that they also exhibit high levels of positional order. In the case of smectic 'A' compounds the alignment is relative to the length of the molecule. Molecules of smectic 'C' compounds are aligned with an additional angle of tilt to the two planes of order.

Initial efforts to capitalise on the bistability of these compounds concentrated on class 'A' materials, relying on their ability to retain their orientation, rather than exploiting any of the properties relating to the order of the molecules, as was the case with nematic techniques. These techniques used a "dynamic scattering" of the molecules to block the passage of light through the cells, a technique that was used in the earliest LCDs. This method aligns the molecules by the application of an electric field to cause the 'light state'. The application of a reversed polarity electric field for a carefully determined period leads to the random re-alignment of the molecules in the reversed direction. The removal of the reverse potential whilst the molecules are in random disarray means that the passage of light through the cell is blocked owing to the random scattering from its intended path. An advantage of this technique, above that of the material's bistability, is the lack of dependency on inefficient polarisers. These displays therefore offered relatively high levels of light transmission. Disadvantages included the need for high potentials to address each element and the slow response of the molecules (typically 50ms).

Class 'C' materials have been the focus of the greatest levels of investment into displays based on this group of materials. Here the order of the molecules is put to effective use. Class 'C'

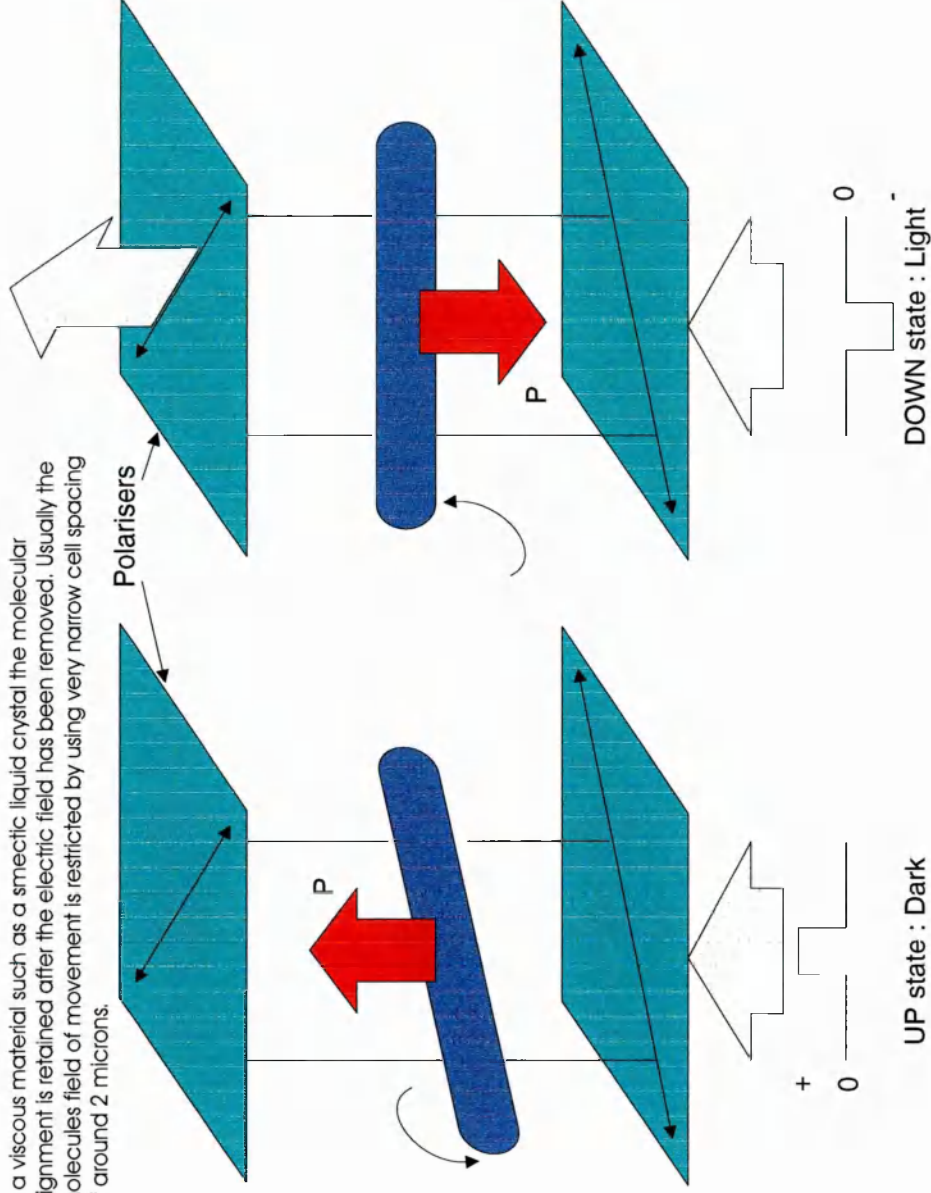
materials exhibit a degree of tilt in the positional order of the molecules. Each molecule is permanently polarised. Naturally these molecules can be made to rotate along a conical path, but by reducing the cell gap of the panel this movement can be restricted to a single plane of movement. The long response times associated with smectic materials are overcome by uniformly twisting the molecules about their axis, as opposed to re-orienting them in a random manner. Fig. (5) shows the basis of operation of such a cell. Because the molecules retain a permanent polarised state in the absence of an electric field they are known as *Ferroelectric*. By reducing the thickness of the cell sufficiently it is possible to restrict the movement of the molecule within a single plane governed by the glass plates. Such molecules possess a moment of polarisation perpendicular to the director. Therefore, the orientation can be changed by the application of electric fields of alternate polarity. By the use of crossed optical polarisers (see 2.1.2) and the optimisation of the birefringent characteristics of the cell to produce a phase shift of 180° both 'light' and 'dark' states can be achieved. Because the orientation of the molecules is uniformly operated, and the range of movement strictly limited, the response of these cells is quicker (typically $50\mu\text{s}$) than that of other methods. However, there remains a great difficulty in controlling such narrow cell gaps (typically $2\mu\text{m}$), and maintaining the *surface stability* under mechanical duress^{vi}. Also, the true bistable nature of the cell means that traditional methods of producing grey scale, by controlling the level of driving voltage, become impractical. One major area of research is into novel methods of creating grey scale using frame rate control and sub-pixelation^{vii}. A major factor, however, in the further development of ferroelectric LCDs (FLCDs) is the relatively high cost, and scarcity of materials to use in production. FLCDs are not currently mass manufactured, so materials are only produced on a relatively small scale, with the associated problems of small batch consistency. Substrate materials are difficult to procure owing to the extremely tight tolerances required to meet the demands of such fine cell gaps. The long term development problems associated with this technology have led to many suppliers discontinuing suitable materials, and subsequently all further development of them.

2.1.5 Refinement of TN and STN Displays

It has been said that the majority of applications use TN type displays, where high levels of information content do not demand high levels of multiplex, leading to compromise on contrast and effective viewing cone. The simplicity of the materials, construction and wider operating temperature range are of higher priority. The study of the electro-optical performance of such materials renders the characteristics shown in Fig. (6), known as the Gooch & Tarry curve. This clearly shows that there are two distinct optimal arrangements for the TN cell. The two dominant variables are the cell thickness

Fig. (5) FLCD cell operation

In a viscous material such as a smectic liquid crystal the molecular alignment is retained after the electric field has been removed. Usually the molecules field of movement is restricted by using very narrow cell spacing of around 2 microns.



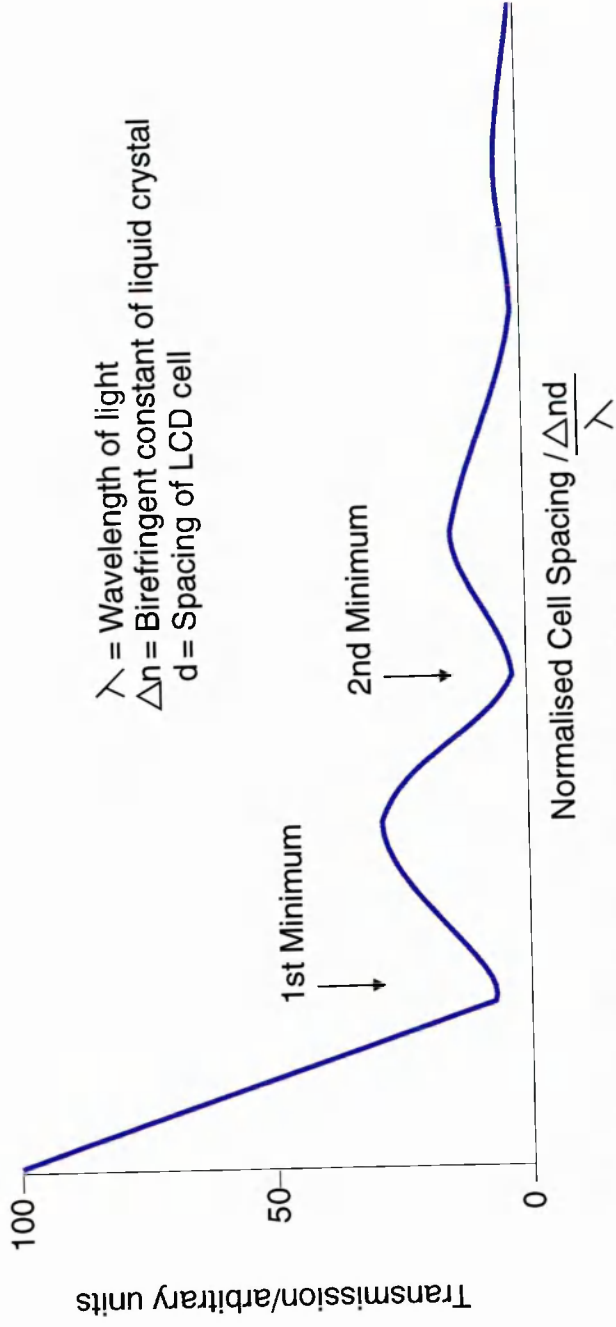


Fig. (6) Gooch and Tarry Curve

This characteristic is typical for all TN type LCDs. Typical cell spacing for a TN LCD is in the range of 11-5 microns. Another important factor illustrated by this characteristic is the dependence of the LCDs performance on the wavelength of incident light. This is of particular importance when designing negative mode TN displays with rear lighting.

and the birefringent index of the LC material. These two optima are referred to as the 1st and 2nd minima respectively. Generally '1st minima' cells exhibit a greater effective viewing cone than '2nd minima' cells. The latter usually exhibit greater levels of contrast. As a result in the past 1st minima cells have been the accepted norm for automotive applications, where the displays are required to be satisfactorily viewed from anywhere within the cabin. Though there are LC materials optimised for use in one or the other mode the dominant concern for the manufacturer remains the cell thickness. 1st minima cells typically require a narrower cell gap than 2nd minima cells. 1st minima cells are therefore more critically affected by non-uniformity in overall cell gap. This makes their application more difficult for 'negative mode' displays, where the active pixels appear light upon a dark background, and a backlight is used to highlight active areas. This is achieved by un-crossing the polarisers. Non-uniformity in cell thickness is more apparent in these types of displays where it is made apparent by the bleed through of light from the rear of the display. A proprietary enhancement of standard TN technology, first developed by VDO Instruments specifically for the automotive market, is MTN (Modulated TN) technology. Here the alignment layer of the display cell is given a non-uniform, textured, finish. This means that the relative position of the LC molecules across the surfaces of the cell is non-uniform. Although in the optimum viewing direction this reduces the contrast it does have the effect of enhancing the acceptable contrast over a much greater viewing angle. This idea is being further developed at the moment with the use of multi-domain alignment treatments. Here the alignment layer is described not by rubbing in a particular direction, with a particular degree of work, but by the use of photosensitive polymers, which allow multiple domains to be described using photolithographic methods.

Above these relatively low levels of multiplex (16:1, or 32:1 in extreme cases) the performance of TN cells becomes unacceptable, though it is difficult to exactly quantify such a subjective measurement. Traditionally this has meant a switch to STN technology, though there has been a move recently to develop 'enhanced' or 'hyper' twisted nematic (ETN or HTN). In such cases the degree of twist introduced to the LC within the cell is increased to around 110° or 120° . This has the effect of improving the contrast, slightly, but more significantly the effective viewing angle. In fact the cell is a compromise between the mechanism employed by TN displays and that employed by STN, the issue being to minimise the birefringent effects so as to eliminate the requirement for optical compensation.

In the case of STN displays the birefringence of the liquid crystal molecules is the dominant optical parameter. Light incident upon the liquid crystal molecules is refracted along the two optical

axes. Because the length of the liquid crystal molecule along each axis is so disproportionate the levels of refraction differ accordingly. Hence the light reaching the far side of the cell has become elliptically polarised. Despite being the basis of operation this is a major drawback of STN technology, restricting the efficiency with which light of various wavelengths exits the cell. Hence the traditional yellow or blue appearance of standard STN cells (although other colours are achievable through adjustment of the polariser axes, these two modes offer the greatest contrast). Until relatively recently this has been an unresolved phenomenon and meant that a true black and white image had been impossible to produce. The effects of this colour distortion can be reduced by using a deep purple polariser as the analyser. The dark elements then appear deep purple whilst the other areas appear neutral. These displays are known as 'silver mode', based on the silver rear polariser that is normally used to reflect ambient light, and offer an appearance similar to the simple TN cells, though with a much improved optical performance. For example, a TN display operated at 100:1 levels of multiplex, and viewed normal to the display would exhibit a contrast ratio in the region of 5:1, whereas a similar STN display would typically achieve greater than 20:1.

In order to produce a true black and white image, and, therefore, to be able to transform this into one with real colour, it is necessary to use one of two techniques recently developed to compensate for birefringent distortion. These are film compensated STN (FSTN) or double layer STN (DSTN).

DSTN represents, perhaps, the most logical step. A secondary STN cell is arranged behind the primary display cell, but with reversed optical properties. Any distortion of light brought about as a result of passing through the primary cell is compensated for when passing through the secondary cell. This second cell is called the 'compensator', and effectively reverses the birefringent consequence of the primary cell. Adding this secondary cell has its obvious drawbacks. It doubles both the effective cell weight and cost, effectively halving production capacity of laminate alone. It also introduces a further critical step to the manufacturing process, as the alignment between the two cells is critical if the compensation is to be effective. There is some small saving in only having to use the one set of polarisers.

In reaction to these drawbacks FSTN was developed. Instead of the secondary cell a sheet of polyester, or polycarbonate film is stuck to the rear of the primary cell. This film has optical characteristics similar to the secondary cell. This film is called a compensation, or retardation film. It is difficult to get a film that satisfactorily compensates the birefringence of every type of STN cell, as the number of variables such as LC, cell gap, polyimide, etc. is large. So there is generally a compromise in quality to be made when choosing this technique over DSTN. But the cost and weight

savings suit it to many applications, especially within portable equipment. The main advantage that DSTN has over FSTN is its performance over an extended temperature range. Because the secondary cell is effectively identical to the primary cell, but reversed, its properties over a range of temperature mirror those of the primary cell. The retardation film used in FSTN has distinctly different thermal characteristics from those of the STN cell, especially at elevated temperatures, where the display can begin to show unsatisfactory changes of colour. Its range is therefore limited at best to around -20°C to $+70^{\circ}\text{C}$. DSTN may be designed to perform well up to the limits of the polariser material, say -35°C to $+85^{\circ}\text{C}$.

2.1.6 Colour LCD

These two monochrome techniques, FSTN and DSTN, form the basis of full colour displays. In order to achieve a full colour display, image pixels are arranged into groups of three and colour filters placed over each in a typical Red, Green, Blue (RGB) format. These 'sub-pixels' provide the necessary primary coordinates for displaying full colour images. The range of colours which can then be displayed depends on the number of grey scales which can be provided by the drive system. STN displays achieve grey scale in two ways. The most commonly used method by far is the analogue address. The level of grey scale is controlled by the level of voltage applied across the cell during a given time period. A more recent development is a digital addressing scheme. Here the time for which the addressing pulse is applied across the cell is controlled. This requires more complex drivers, but offers the potential for a more stable and predictable driving scheme, as it is less sensitive to thermal variation, or variation in power supply.

2.1.6.1 Controlled Birefringent Colour LCDs

A third method has been discussed, and produced for limited applications. This is known as 'tuned birefringence'. This technique employs up to three separate cells with specific birefringent properties, using colour selective polarisers, to achieve the three subtractive primary colours (Cyan, Yellow and Magenta) laminated together. These 'stacked' displays offer extremely good colour saturation, but the obvious cost, and weight penalties are prohibitive in most applications. In addition, there is a compromise in efficiency owing to the numerous polarisers, and a problem of parallax which makes them unsuitable for direct view applications. They have found a niche in projection type displays where powerful arc lamps can be used to provide adequate back lighting, and parallax is not apparent.

A further recent development has been electrically controlled bi-refracting colour LCDs. In this case the parameters of the LCD are carefully controlled, and the bi-refracting characteristics exaggerated.

A typical STN cell has a bi-refrident characteristic, Δn (Δn = birefringent constant of any given LC; d = gap between cell substrates; cf Fig. 6), of between 0.6-0.9, and can be made to exhibit gray scale by controlling the drive voltage, or the frame frequency of associated pixels. By creating a cell with a large Δn value (typically 1.4-1.6) it is possible to obtain different colours, as opposed to gray scale over a narrow operating voltage range. A great benefit of not needing colour filters is that there is no need for a backlight under good ambient lighting. This has created a whole new application area for extreme low power applications, such as handheld GPS with cartographic reproduction. The advantages for automotive applications, where high levels of ambient lighting may be present, are extremely attractive. Also, the additional cost of the LCD is almost negligible, and additional film compensation is not required, though it does help improve the possible extent of saturation of primary colour. Without film compensation the colours are vivid, but tend more towards a secondary colour hue. A further current limitation is in viewing angle; because the colour is dependent on molecular orientation the colour may change significantly with viewing angle. Optically compensated versions perform better in this respect.

2.1.6.2 Active Matrix Colour LCDs

Conventional LCDs such as those of TN and STN so far described have many drawbacks. The greatest of these is the need constantly to address each 'active' pixel, in much the same way as with dynamic RAM. Because of this, the viscosity of the LC fluid needs to be kept at a certain level to ensure that the pixel has not turned off completely before the next addressing pulse comes along. Also, there is the problem of 'crosstalk' that has already been mentioned. These factors combine to compromise the clarity of the image. If the rotational viscosity of the fluid is too low then the contrast is affected. If it is too high then there is 'ghosting' whenever the image is updated or moved. This latter fact is particularly restrictive when considering video images, or the use of a mouse cursor. Each of these factors could be minimised if the pixel state could be made non-volatile throughout a frame period. A solution to these problems has been the development of 'active matrix' LCDs (AMLCDs).

Active matrix LCDs have a thin film transistor (TFT) or diode situated at each pixel. Each semiconducting element is fabricated by deposition of silicon (usually) upon the surface of the glass using methods developed from the semiconductor industry. Generally this silicon is of an amorphous nature, though it is also possible to deposit polycrystalline silicon. Polycrystalline semiconducting material can also be formed by annealing the deposited amorphous silicon. Fig. (7) illustrates the circuit diagram model of such an arrangement using TFTs, and Fig. (8) shows the cell structure. These active elements effectively isolate each pixel from the rest of the array. Hence 'crosstalk' is eliminated,

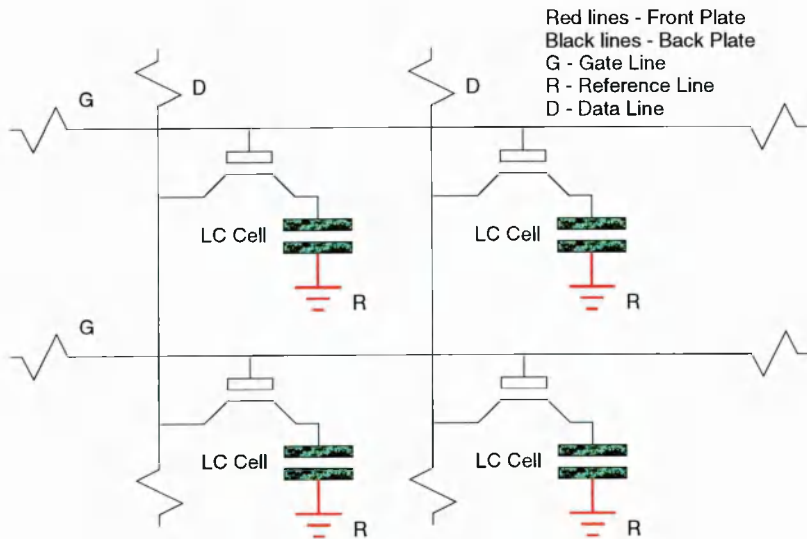


Fig. (7) Architecture of conventional TFT LCD

This represents a very simplified equivalent circuit for a conventional TFT Active Matrix LCD. It does not show any detail of the various associated parasitic capacitances.

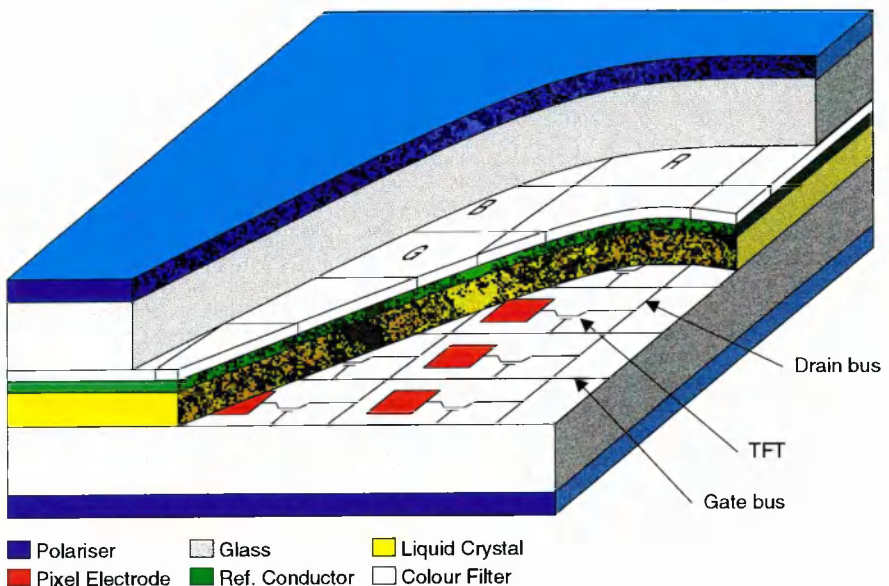


Fig. (8) TFT LCD Structure

Cross-section showing the typical structure of a TFT Active Matrix LCD. The specific construction of the thin film fabrication has been omitted for simplicity.

and because the charge across the cell at each pixel can be isolated the display has inherent memory. So the molecules of each pixel do not readily relax back to their natural state. This allows the use of LC fluids with a much lower rotational viscosity, and, therefore, enables high switching speeds capable of recreating video images. Because the contrast levels of such displays are orders of magnitude better than traditional 'passive matrix' LCDs (PMLCDs) there is no longer the need to use STN type cells. This means simple TN cells can be used without the need to compensate for the severe birefringent effects of STN.

Whilst the improvement in performance exhibited by these displays over traditional PMLCDs can be significant so is the additional cost. Apart from the huge increase in fabrication overhead, there is a similar burden imposed by the poor manufacturing yields currently being achieved. Until relatively recently such displays have only been truly economically viable for small size displays such as those found in camera viewfinders and portable TV sets. However, manufacturers now have commercially available displays of 10.5" diagonal, and above. Many such products can be found in high specification portable computers. The phenomenal levels of investment that have been made into this technology are now starting to show signs of maturity. Few manufacturers of Notebook computers now have offerings which do not feature the option of an AMLCD. This rapid development has spawned different branches of display technology in its own right. There are, as mentioned, displays that use TFT or diode addressing. There are also displays that use TFTs that are fabricated from epitaxially grown polysilicon (p-Si), as opposed to the usual amorphous-silicon (a-Si), or even cadmium selenide (CdSe). Both p-Si, and CdSe demonstrate increased carrier mobility over a-Si and are capable of much higher relative switching speeds. Consequently they can be fabricated in a smaller feature size than a-Si devices yet achieve a similar performance. The drawback is the higher temperatures required to form p-Si, though laser annealing is having a significant impact here. CdSe remains relatively unproved in manufacturing, and has the stigma of being highly toxic. Use is limited at present to smaller 1" - 2" diagonal screen sizes for p-Si, and the laboratory for CdSe.

Production yields are still the overpowering burden of the AMLCD manufacturer. Each step up in screen size requires an order of magnitude improvement in manufacturing processing. Sharp, who are the undisputed leaders in this field, recently announced a prototype 28" diagonal a-Si AMLCD made of two individual cells, and Samsung a single cell 22" diagonal version.

Other techniques have not been slow to develop and snatch niches in this burgeoning market. Kopin, a small 'start-up' company from the USA, recently introduced AMLCDs based on single-crystal silicon. Here the 'active-matrix' is formed using wafers of silicon identical to those used for the

fabrication of semiconductor ICs. The passive substrate material is then removed, and the now transparent active matrix is transferred to the glass substrate of the display. Of course these can only be fabricated in very small screen sizes, but their target market is viewfinders and projection systems.

2.1.6.3 Passive Matrix Colour LCDs

Efforts have been continuing to improve the performance of PMLCD, especially with the production of 'split screen' or 'dual scan' displays, where the vertical electrodes are split horizontally across the screen, and the two halves addressed separately, effectively halving the multiplex ratio. Using the same techniques of colour filtering and gray scale control as AMLCD, full colour displays can be produced very successfully, and without the need for the highly complex manufacturing plant required to fabricate AMLCD. The attendant yields of this much more conventional plant, and less complex technology, are significantly better than those achieved in the manufacture of AMLCD. However, they do require some form of birefringence compensation in order to get good primary colour saturation. A lack of 'memory' in the cell also leads to a poorer contrast and ghosting in moving images. A recent development in addressing techniques has revitalised the development of PMLCDs, however. This is "Active Addressing", or "Multi-Line Addressing". Instead of only addressing each pixel with a single pulse during each frame period (Alt/Pleshko technique), a complicated algorithm (Walsh functions) is used to calculate an addressing scheme which provides a series of smaller pulses throughout each frame period^{viii}. Fig (9) illustrates this drive technique. It obviously improves contrast, but because the size of the addressing pulse is now greatly reduced crosstalk is minimised also. An added benefit is that cheaper driver ICs can be fabricated due to the lower drive voltages required.

2.1.6.4 Polymer Dispersed LCDs

A further LCD technique which has received significant development in recent times uses LC fluids sealed in a polymer resin. The LC is held in tiny droplets within the viscous polymer material. It allows the active cell medium to be sandwiched between flexible plastic substrates without the need for rigid spacers to hold the cell gap uniformly. It operates on the principle of '*Dynamic Scattering*' (DS) previously described. Consequently it relinquishes the reliance on polarisers and, therefore, does not require the substrate to be prepared to align the LC molecules. This means that such cells possess good transmission characteristics, and excellent viewing angle performance. The relatively poor contrast, though, makes them unsuitable for applications requiring backlighting. The inefficient mechanism of polymer resin encapsulation means a high percentage of incident light manages to traverse the cell without passing through the LC droplets. It is showing enormous potential for outdoor

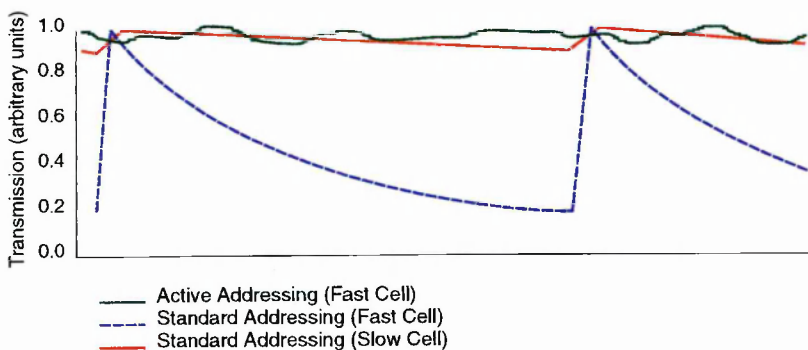
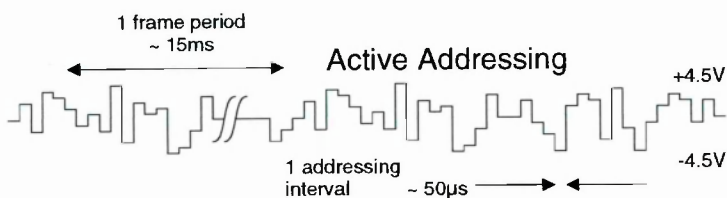
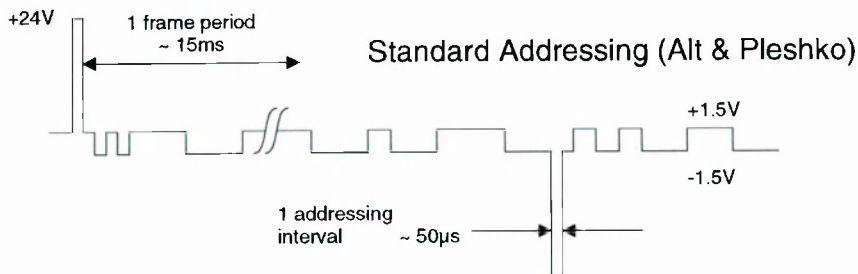


Fig. (9) Active Addressing vs Standard

Active addressing, also known as 'multi-line addressing', requires the use of complex mathematical algorithms. As yet this has proven to be difficult to achieve economically using conventional semiconductor technology. This is set to change now that sub micron feature sizes are becoming more easily achieved.

applications, such as road signs because of its good performance in reflective mode, and because of its freedom from UV sensitive polarisers, and also in membrane keypads because of the added ruggedness lent by the polymer resin. These cells are usually considerably thicker, by 10s of microns, than standard TN, or STN, cells, and the materials required are generally more viscous, therefore, they require higher voltages to operate them satisfactorily, typically in the range 70V-80V. They illustrate well the manner in which the various techniques using liquid crystal materials have evolved to meet the specific demands.

2.1.6.5 Backlights For LCDs

Although LCDs require very little power in themselves, relatively speaking, being non-emissive they require some form of additional illumination for the visible image to be satisfactory. For applications such as wrist watches and calculators a reflective display can make the most of ambient lighting. The ability to modulate ambient light is a great advantage in applications such as parking meters and petrol pumps, where high levels of ambient light would 'washout' most emissive images.

In order to reproduce full colour, or even true black and white, images it is necessary to provide some sort of supplementary light source. Techniques for illuminating an LCD are as numerous as those of the LCD itself. Possibly the least expensive, in terms of component cost, and most easily integrated source is the ubiquitous tungsten filament lamp, but these are notoriously inefficient, unreliable and hot. In addition they have very poor lifetime and colour characteristics. High intensity halogen variants are used extensively for projection LCDs, as are various types of metal halide discharge lamps. This is usually limited to applications where there is a premium on total available light, and heat and power consumption are less critical, such as head-up displays (HUD) and projection TV sets. A large amount of the research into projection type displays is going into the production of large format HDTV sets.

Light emitting diodes (LEDs) (see section 2.2) have replaced filament lamps in a vast majority of applications, owing to their remarkable lifetime (250,000 hours and more), relatively high efficiency and low operating voltage and power dissipation. They are limited in their range of colour and the maximum amount of radiant light they can produce, nevertheless the great majority of instrumentation applications use them as either primary or secondary light sources.

Electroluminescent (EL) lamps (see section 2.5) represent perhaps the ideal form of backlighting for LCDs, but they too suffer from poor lifetime and radiance characteristics. Typically they are only rated for 7000 hours. In addition they require circuitry capable of generating the necessary high voltage, high frequency drive format - see section 2.5. Future developments in EL phosphor

efficiency and complex polymers still have the potential to make the most of the extreme thinness, even light distribution and ruggedness of this technology.

In the majority of applications there are miniature, cold cathode, variants of household fluorescent lamps. Typical diameters range between 10mm and 2mm. As with household lamps they are capable of providing relatively high levels of radiance across a broad, white, spectrum. Tubes developed specifically for full colour applications have specially selected blends of phosphors which emit light predominantly at three different wavelengths matched to the optimum efficiencies of the colour filters incorporated into the LCD. They have good lifetime characteristics (20,000 hours) and produce very little heat. When used in association with an acrylic light guide they also offer a very slim, and lightweight backlighting solution. They also require additional circuitry to generate the higher voltage and high frequency drive potential, to achieve the breakdown voltage which leads to the discharge between the electrodes whilst reducing flicker and improving phosphor efficiency.

A variation currently used for full colour, high information content displays is the hot cathode fluorescent lamp (HCFL). Here the cathodes are heated to give a higher electron output and better brightness control. There is a penalty in terms power consumption and lifetime, for this marked improvement in light output. The net effect of this additional demand is to bring the power consumption of a typical LCD more in line with that of the various emissive display techniques, increasing the weight and size, as well as the cost of the finished product.

2.2 Light Emitting Diodes (LEDs)

In terms of reliability and efficiency no display element comes close to matching the LED. Lifetimes are in the region of 250,000 hours and efficiencies approach 20% for some products. Few, if any can match its switching speed.

Early pocket calculators and digital watches used LEDs, and for some years the LED has been used to replace incandescent lamps as indicators. Almost all watches and calculators these days of course use simple LCDs for greater power saving. Some applications have seen LEDs replacing incandescent lamps as warning lamps for automotive stop lights, Fig. (10).

Only recently though has the LED begun to find application in integrated display systems as the active element. These applications themselves are still limited by the lack of a bright, blue LED able to match the performance of devices which emit light in the red through to green parts of the spectrum. The enormous increase in the efficiency of these devices has led to their increasing use in large area displays for public information, up to several metres in diagonal. Each pixel consists of a



Fig. (10) LED Stoplight
Use of high brightness LEDs
to replace incandescent
lamps for high mounted
automotive stoplights is now
common across a wide
range of cars of all classes.

discrete LED lamp, or die. LEDs of different wavelength have been combined to form multicolour displays capable of reproducing video images.

LEDs are now available which operate at wavelengths of 555nm, pure green, to devices that operate in the infra-red region at around 1350nm. The maximum brightness from these devices varies depending on wavelength. Originally red LEDs were the brightest visible devices, with some capable of 10 candela (cd). Recent improvements in materials, and the introduction of quaternary materials, have led to the introduction of amber LEDs capable of 15cd. Green LEDs are still limited to around 1cd. Many manufacturers have introduced blue LEDs recently fabricated from silicon carbide (SiC), as opposed to the normally gallium (Ga) based products, but these devices still rarely achieve a brightness greater than 15mcd-20mcd. Nichia Chemicals of Japan recently announced a blue LED device fabricated from InGaN (indium gallium nitride)¹⁸ with an emitted wavelength of 450nm. The documented lifetime of this device was only 3,000 hours, though service life easily exceeding 10,000 hours has been achieved in the laboratory. The main demand for these devices is in the area of full colour, large area displays. In the event of a diode laser being developed on this basis there is a significant demand for reading optical storage disks, where the shorter wavelength allows the capacity of readable data to be increased substantially.

One of the original developments which was responsible for improving the efficiency of LEDs was the fabrication of '*double-hetero junction*' diode structures⁸. Subsequent improvements have been the use of improved epitaxial crystal growth techniques, the removal of the light absorbing substrate material through etching and the introduction of more complex compounds like InGaAlP (indium gallium aluminium phosphide).

It can be expected that the recent improvements in materials will result in a rapid increase in the use of LEDs for large area public information displays. Once manufacturing yields and lifetime for these new materials have been improved there will be a significant demand for their use in personal entertainment displays.

Active matrix LCDs have shown that it is possible to create semiconducting devices over large areas suitable for use in smaller display applications. What if this technology were developed to fabricate large areas of LED matrix instead of thin film transistors or diodes? Of course the methods currently used for such matrices only make possible the fabrication of semiconducting materials of an amorphous or polycrystalline nature, which would be unsuitable for LEDs of adequate efficiency to overcome internal absorption. But improvements in preparation of such materials, such as laser annealing of amorphous compounds suggests there is considerable long term potential. Light emitting

diodes formed from organic materials based on silicon nitride^{xi} on glass substrates and the development of light emitting polymers offer new options which are being actively pursued.

A drawback of present LED displays is the problem of power distribution to the active elements. Because LEDs operate at relatively low voltage they require much higher levels of current to be supplied across the large expanses of screen to achieve satisfactory brightness. LEDs operate most effectively at around 20mA, though this is very much dependent on die area. To provide current for, say, a VGA compatible resolution (640x480), would require over 10A for each colour. Based on the standard 5mm LED lamp pitch this would render a screen size of approximately 10m x 7.5m. These devices tend to be quite bulky, requiring substantial, high current capacity power supplies. It also means that it is difficult to achieve anything but low levels of integration for the associated drivers. For example, it is quite possible to integrate an LCD driver with 200 outputs. It would be very difficult to achieve a level of integration of more than 12-16 outputs for an equivalent LED driver, owing to the output stages need to sink, or source this relatively large current. Even today's LCD driver ICs, which are required to drive currents of the magnitude of 10^{-6} of that required by LEDs, are pin limited, with the vast majority of the useful IC area being taken up by the output stages. This severely limits the capacity of the IC to dissipate the associated heat, which means more substantial packaging is required, and adds considerable mechanical bulk and cost to the arrangement. Also, because of the high current required, these drivers need to be situated local to the LED they are operating, to avoid significant voltage drop along the conductors affecting the grey scale of the image.

Such drive schemes are, nevertheless, relatively simple. LEDs have far superior performance in terms of switching and grey scale, and in all cases, except currently that of the blue LED, a far superior lifetime.

In the past LEDs have lost market share in certain niche areas to VFDs (see section 2.3). Improvements in the performance and price of LEDs, however, are now seeing them win back ground from VFDs in automotive applications for simple digital meters such as odometers and clocks.

2.3 Vacuum Fluorescent Displays (VFDs)

Since their introduction in the 1960s, VFDs have been used in applications where a higher degree of image quality was required. They were originally developed to replace LED displays in clocks and calculators, being more versatile and less expensive to manufacture, owing to the use of mature screen printing techniques for the application of the phosphor materials which are responsible for the fluorescence. This became increasingly acute as the levels of information required increased.

Because the phosphor used as the light emitting medium is a broad band emitter these displays can be filtered to produce a broader colour range than that of LED. Certainly this was an asset when VFDs were first introduced, when only red LEDs had previously offered sufficient brightness.

The operating mechanism of the VFD is essentially that of the thermionic valve, or triode, see Fig. (11). A filament wire acts as the cathode producing electrons and a grid electrode accelerates, or retards, the electrons as they move towards the phosphor coated anodes. All of this is contained in an evacuated glass package, or tube, sealed with 'frit glass'[^]. Light emission is a result of the recombination of electrons liberated by external bombardment with the ionised atoms within the phosphors. In most displays of this type the phosphor used emits light across a broad band of the spectrum, resulting in a blue-green appearance. This has the advantage of allowing filters to be used to give a specific desired colour, even white, though in order to optimise the light output it is usually filtered to blue or green. Most colour phosphors have been developed for CRT applications from sulphides ($\text{ZnMgF}_3\text{:Mn}$, ZnCdS:Cd , for example). These compounds give off emissions which are poisonous to the electron source. This effect is more significant in VFD applications than CRT owing to the closer proximity of the electron source.

The 'rare earth' materials used in phosphor compounds produce light with this blue/green emission. To achieve spectral emission of a different wavelength from such materials it is necessary to introduce chemical dopants. This reduces both the efficiency of the phosphor and its lifetime. Therefore in the past it has not been possible to produce a display capable of creating a full colour image.

Unlike the CRT, which uses beam potentials in the region of 25kV to 35kV to accelerate the electrons from the 'gun', the VFD operates with potentials between 12V to 150V. Work is, therefore, going on to improve the efficiency of these 'low voltage' phosphors, and develop phosphor materials with physically smaller molecules, so as to maximise the number of emissive recombinations within a given surface area^{xiii}.

Because of electro-mechanical constraints, VFDs larger than 6" diagonal capable of high information content are uncommon at present. This stems from the thermal distortion and destruction of key components, such as the filaments and grids. The reasons for this are the increased current densities required to produce the greater number of electrons from filaments which need to be fine enough to avoid visual detection. Also the increased voltage required across the grids to maintain brightness at higher levels of multiplex across larger screen areas causes the grid structures to heat up,

[^] Frit glass is a ceramic paste which forms a solid hermetic seal when fired in an oven at between 300°C to 400°C.

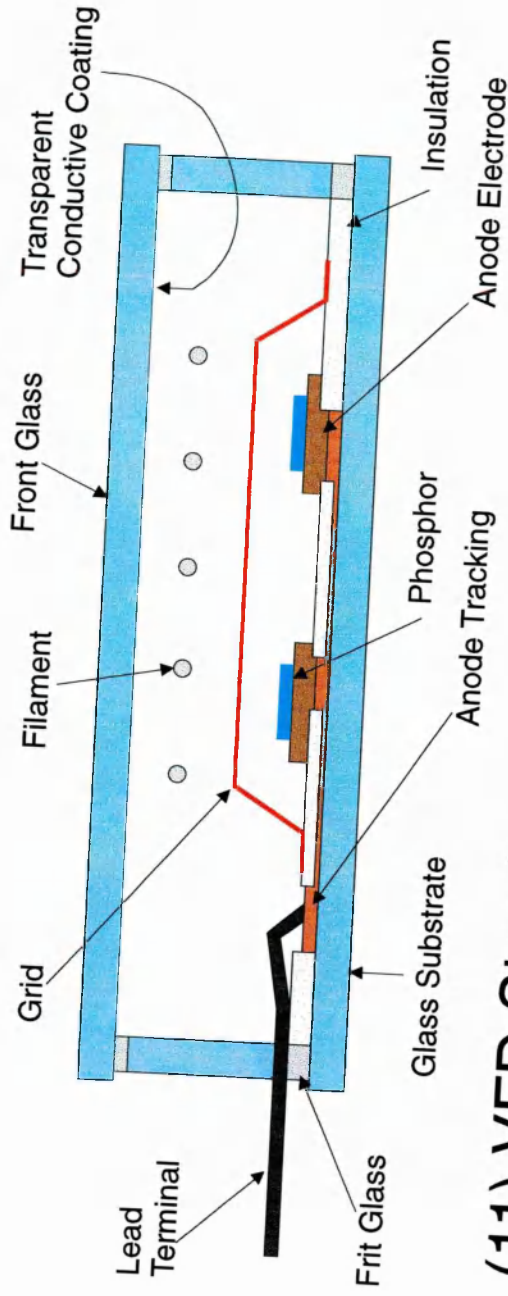


Fig. (11) VFD Structure

Showing basic construction of VFD cell and configuration of main components

and consequently distort. In order to minimise the mechanical bulk of the display tolerances are kept extremely tight, and hence any amount of physical distortion can cause internal shorting, with catastrophic results. An additional overhead to pay for increased display area is the proportional increase in glass thickness required to keep the mechanical integrity of the evacuated glass tube. Yet another disadvantage is the need to continuously power the cathode filament, leading to a poor power efficiency.

These constraints, coupled to the bulk of the low integrated, high voltage drivers have been a major drawback. The majority of electronic components have been subject to substantial improvements in recent years, and VFDs are no exception. Improvements in the assembly and structure of these devices are showing signs of increasing potential (see FED later). The Electronics Industry Association of Japan (EIAJ) predicts that the introduction of new electron sources will lead to the introduction of a 17" high information content VFD with a cell thickness of around 2mm by the year 2000^{xiii}. Similar improvements have been made in the integration of the drive electronics. It is now possible to source ultra thin surface-mount (SMT) packages which integrate up to 100 outputs in a single package.

Traditionally VFDs are viewed from above the cathode filaments, with the phosphors printed onto metallic conductors at the rear of the chamber. The conductors help to reflect the light generated. Obvious problems with this arrangement are the visibility of both the cathode filaments and the grids. Another problem with this mode of view is the parallax caused by the glass surface. By making the anode electrodes transparent, utilising ITO, as used in LCDs, it is possible to minimise the effects of parallax, and remove the filaments and grids from sight, by then viewing the image through the rear glass substrate.

Parallax due to the rear substrate is minimal, and the viewing angle of such displays is consequently comparable to that of CRTs. Their ability to produce a high contrast image over wide viewing angles has led to VFDs being used extensively for consumer applications, where, for example, they are used almost exclusively in VCRs.

A further development that has recently reached the market place is that of 'Rib Grid'^{xiv} architecture. Here the grid structure is supported from the rear substrate by a rigid platform, similar to the way that the individual cells are created for PDPs (see section 2.4). The potential offered by such an arrangement is to enable the viewing area of such displays to be increased substantially and to enable the cross-sectional area of a VFD to be reduced.

One further area of VFD application is in the area of large area full colour displays, such as those that provide video images to large outdoor venues. These images are made up from individual

picture tubes similar to the thermionic triodes inside traditional TV sets. The ends of these tubes are coated with phosphor and the drive voltage is in the range of 10kV. They are in effect a cross between what we understand to be a VFD and a CRT. Sony in particular market this technology under the name Jumbotron™, and they are now becoming commonplace in many major sporting arenas.

In their currently accepted guise VFDs will be unlikely to progress beyond the traditional niche markets in consumer electronics, automotive instrumentation and electronic point of sale (EPOS). It is interesting to note that although 100% of all display components used by Ford Motor Company in Europe are LCDs, 95% of all used in the US are VFDs. More significantly the developments associated with this display technology, and vacuum microelectronics generally, have huge potential. This will be discussed at greater length in later sections.

2.4 Plasma Discharge Panels (PDPs)

Similar in principle to the fluorescent gas discharge tubes used in domestic lighting and the cold cathode fluorescent lamps described on p.17, PDPs have been under development as display elements for longer than any of the other flat panel electronic display (FPED) technologies. Though sharing the same mechanism for producing light there are in fact two techniques employed in producing a PDP. The difference is in how the discharge is achieved, either by an AC, or DC driving method. The basic principle is to seal a noble gas between two electrodes (anode and cathode). A high voltage discharge between the electrodes causes light to be emitted by the gas which is excited and ionised by electron impact. The gas used in most cases is neon (Ne), which produces a reddish/orange light, with small amounts of argon (Ar) or xenon (Xe) which help to lower the voltage necessary to maintain the discharge. In the case of the DC method the emission of light continues for as long as the high voltage discharge is maintained. This can be for a period beyond that of the application of a trigger pulse, depending on the discharge characteristics of the cell. The problem with this scheme is the non-linearity of light emission. That is, once the cell threshold has been reached discharge occurs and light is emitted. It is fundamentally a difficult mechanism to control to the point where satisfactory grey scale is achieved.

AC driven PDPs have between the electrodes and the noble gas, layers of dielectric which are applied to protect the electrodes from damage due to ion bombardment. The surfaces of the dielectric accumulate negative charge from energetic, mobile electrons. Ions arrive more slowly. Potentials therefore build up to slow the arrival of further electrons until a state of equilibrium occurs when electron and ion flow is equal. At low frequencies the discharge can fail between cycles. Therefore,

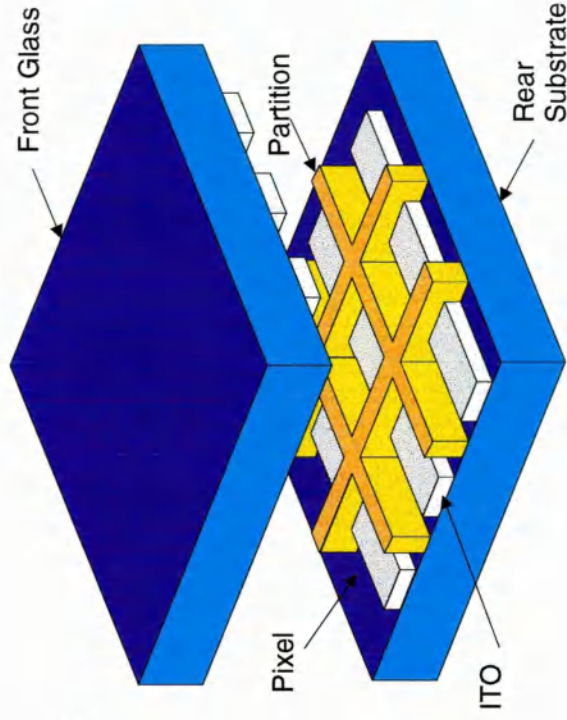
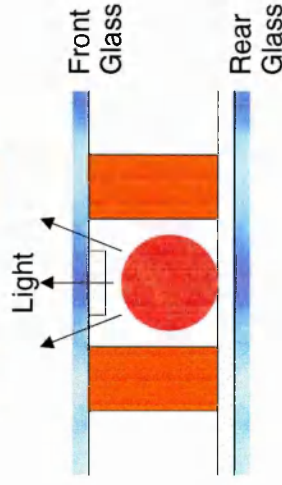
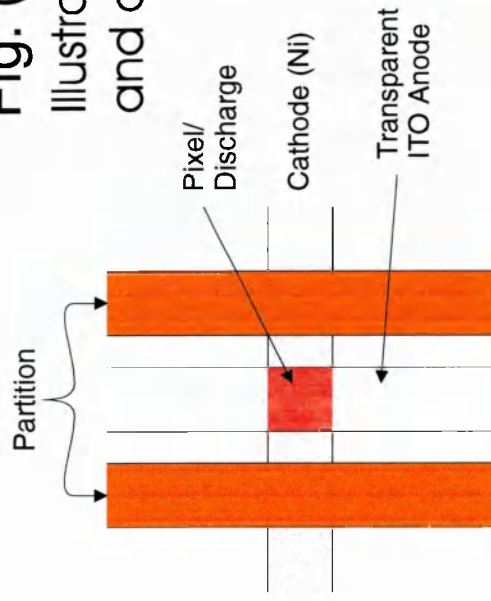
higher frequency drive characteristics lead to improved performance. Also the human eye integrates the amount of visible light it receives over a period of around 25ms, typically, and so smoothes out any change in light emission over the shorter cycle time. With the change in polarity the discharge is reversed. A symmetrical drive scheme improves the performance and lifetime of these displays as there is less degradation due to the erosion of the electrodes by high energy ions.

Once discharge has been achieved with the use of a triggering pulse the cell continues to conduct through the AC cycle. The capacitive characteristics of the cell lead to a build up of charge across the electrodes which leads to the eventual extinction of the discharge when the stored charge reduces the discharge potential below that required. The emission of light is restored by this stored charge once the AC waveform reverses polarity during the second half cycle when it automatically triggers the discharge once more. This is referred to as the 'memory function' of the display. Improvements in the switching speed of the cell, and hence the stability of the display, can be made by 'priming' each cell to a level just below the discharge potential threshold on the cycle prior to its address. This effectively prepares the cell reducing the delay before a discharge potential level occurs across the cell. Fig (12) illustrates the construction of typical AC and DC PDPs.

Historically PDPs have been used predominantly in instrumentation and EPOS applications because of their bright appearance under artificial lighting conditions and their legibility over a wide viewing angle. Because of their limited colour range, need for high drive voltages and poor contrast much of these applications have been taken over by the use of VFDs. This has not led to PDPs becoming obsolete. PDPs employ relatively mature manufacturing processes in their assembly, and because the cell substrates are held at a uniform cell spacing by the cell partition and rely on high voltage driving, as opposed to high current, they are suitable for large area, high resolution applications, similar to those of CRTs. Additionally, the absence of delicate grid and filament structures, or polarisers means the robustness of their construction is not compromised. These characteristics alone had, until the recent introduction of AMLCDs, seen their preferred use in portable computers. Many such products manufactured for military applications still use PDPs for these reasons. However, the amount of light produced by such displays is a function of the volume of gas present. This results in the active cell being significantly 3 dimensional in nature, which leads to an isotropic distribution of light, and hence a loss of contrast. It also defines the minimum cell size capable of producing satisfactory light emission.

Full colour PDPs produce light in a manner different from the monochrome equivalent. To obtain colour the transparent anode is coated with a phosphor. The noble gas mixture within the cell is

Fig. (12) PDP Construction
 Illustrating mechanism of operation
 and cross-section of cell construction



changed so that the discharge causes light to be emitted predominantly in the ultra-violet spectrum. Ultra-violet light excites the phosphor causing it to emit light of the appropriate wavelengths to achieve the necessary RGB format of full colour displays. This mechanism is also more efficient for monochrome displays if green emitting phosphor is used, this is due to the eye's greater photopic sensitivity to green light than red, or blue, and the greater efficiency of this type of mechanism to produce light in the ultra-violet range of the spectrum rather than the visible 'neon red'. If it is assumed that the same quantum efficiency is achieved for each red, green, or blue pixel, the introduction of green to one-third of the screen area improves the efficiency significantly over the traditional red display. It has also proved to be more appealing visually, and facilitated their use as direct replacements for similar monochrome CRT displays.

The ability of the PDP to perform with a higher luminous efficacy for multi-colour applications relative to the basic monochrome device is unique amongst the various display technologies, and has led to an increase in development of PDP for full colour displays with large viewing areas. Lifetimes for such devices are currently quoted in the region of 10,000 hours, coupled to a low cost potential^{xv} (relative to TFT) for large areas displays. Much development is now being carried out into their use for large area, wide screen TV monitors for direct view^{xvi xvii}. In fact commercial HDTV sets employing PDP will become commercially available, at least within the Japanese market, by the fourth quarter '96, with products from Fujitsu, NEC, Mitsubishi and Oki/NHK.

2.5 Electroluminescent Displays (EL)

Besides LEDs, electroluminescent displays are the only other truly solid state display technique, with no need for liquids, gas discharges or evacuated chambers. The mechanism by which EL displays produce light is very similar to that of the LED.

As with the PDP there are both AC and DC derivatives of EL displays, as well as thick film and thin film techniques for preparing the luminescent solid. The AC thin-film EL (ACTFEL™)^{xviii} displays make up the overwhelming majority of devices being marketed.

In a similar manner to AC PDPs, ACTFEL displays sandwich the active display medium, essentially a phosphor, between dielectric layers and the electrodes. Fig. (13) illustrates the construction of a typical EL display cell. A peak AC potential, exceeding a certain threshold level, accelerates free electrons to several electron volts. When an electron with a very high kinetic energy collides with an activator atom the latter may receive, and store, the energy in a process called collision

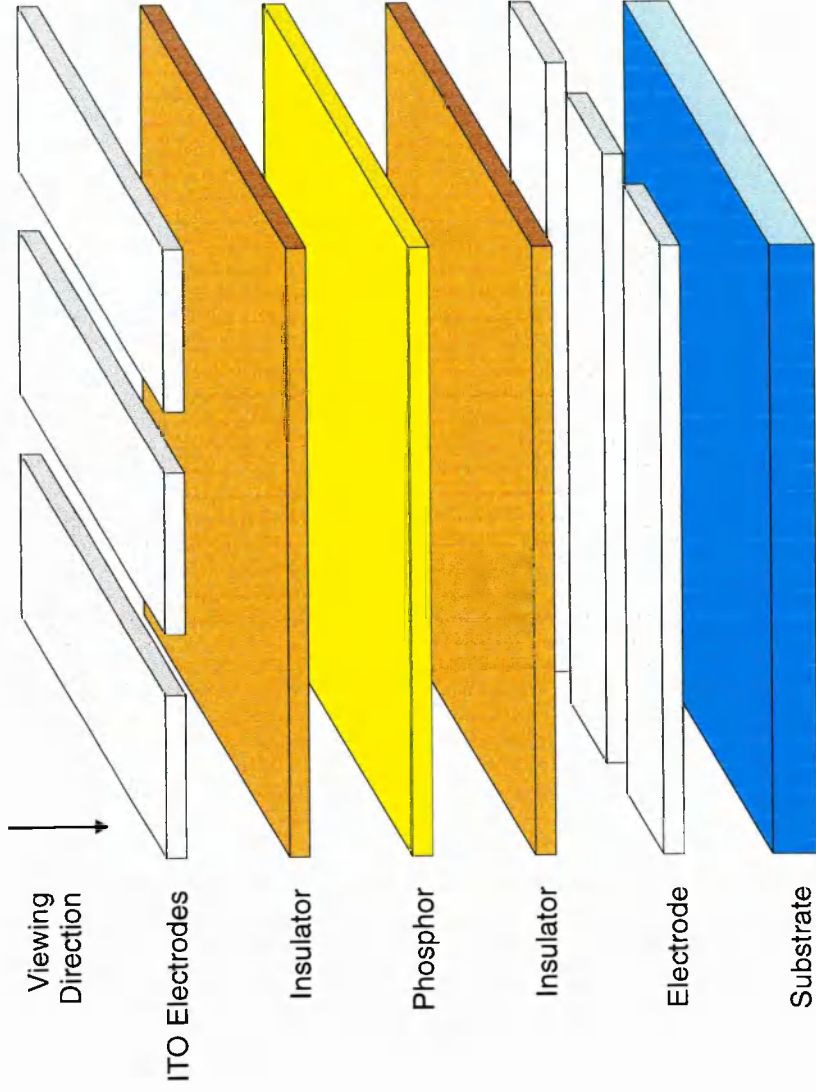


Fig. (13) Structure Of Thin Film EL Display

Simplified diagram of ACTFEL cell structure. To improve performance some manufacturers etch thin aluminium tracks along the ITO to improve conductivity. Also, 'black masks' are used to reduce reflection from rear electrodes, and neutral density filters to reduce reflection from phosphors.

excitation. The activator, after a certain period of time, relaxes to its former stable state, with the liberated energy being given up in the form of a photon of light. Upon the removal of the peak AC voltage such collision excitation ceases. To avoid the electrical/chemical degradation of the phosphor this is repeated with a peak AC voltage of reversed polarity. Again, as with PDPs the mechanism for producing light emission through excitation is difficult to control sufficiently to allow satisfactory grey scale control.

In order to gain a sufficient kinetic energy of an accelerated electron relatively high potentials of the order of 70V - 80V are required. Until recently very few EL driver ICs of any significant integration had been available, so PDP drivers using around 160V had been used. To achieve a visually stable display AC frequencies of the order of 500Hz are required.

A variety of colours is available, including white, yellow, blue, etc. However, only yellow is available in the form of a reconfigurable display. This employs zinc sulphide (ZnS) as the phosphor base, which has considerable lifetime and luminous output advantages over the other colours.

A problem which may be experienced with AC driven EL displays, and not DCEL, is catastrophic breakdown, due to the failure of the dielectric layer within the cell, which results in the permanent loss of picture elements.

ACTFEL operates on the basis of the cell as an imperfect capacitor, whereas DCEL treats the phosphor layer between the electrodes purely as a resistive component, although there is of course some capacitance associated with the cell in this case also. There is no dielectric layer, and the structure is somewhat simpler^{xix}. In addition the production process for DCEL requires that the phosphor only be screen printed on to the substrate (thick film application), which is considerably less expensive than the thin film method required by ACTFEL. ACTFEL displays, however, exhibit superior contrast due to the very thin nature of the phosphor used.

Historically DCEL has been impractical owing to the poor operating lifetime of suitable EL phosphors. Improvements in several areas have led to renewed interest in this method, however. Both the phosphor materials and drive techniques have been improved significantly. But the most important development has been in the preparation of the phosphor layer. By applying a large DC potential across the cell a 'hardened' barrier layer of phosphor is created. This hardening of the phosphor layer to a specific depth is referred to as 'forming', and improves the operating lifetime of the phosphor. Present drive techniques detect cell brightness on power up and adjust the level of drive voltage to compensate for any degradation in luminosity. This again prolongs the useful lifetime of the display, but cannot compensate for the effects of etching across commonly used areas of the display, which has the effect of

showing a retained image. These improvements coupled to the simplified production process have brought EL display prices more in line with those of monochrome DSTN LCDs. It should be mentioned that such problems as repetitive pattern etching are greatly reduced by using ACTFEL, which uses symmetrical switching waveforms that do not cause the same levels of phosphor degradation. This problem alone has meant that little market penetration has been made by DCEL up to the present moment.

No information is currently available to suggest that full, or multi-colour DCEL, is practical, though in principle there is no reason why such devices should not be possible. ACTFEL devices have been demonstrated that achieve colour in a variety of ways. By using organic filters in association with a yellow ZnS EL display multi-colour displays have been demonstrated showing yellow, green and red, as a result of the relatively broad spectrum emitted by such phosphor materials. Also, white EL phosphors have been used in conjunction with filters to achieve a full colour display. Finally true full colour displays have been achieved using RGB EL phosphors, though both operating lifetime and brightness are currently unacceptably poor.

The problem of poor luminous intensity from such displays is compounded under conditions of high ambient lighting. The use of reflective electrode materials is a major contribution to loss of contrast and clarity under these conditions. Traditionally these have been of aluminium, and act as a mirror to incident ambient light as well as emitted light. This problem has been tackled in a number of manners. Using 'neutral density' filters (typically 50%) placed in front of the display, and applying a black layer between the phosphor and the electrode are two of the more effective methods. The use of neutral density filters has been shown to improve contrast ratios to the order of 40:1. The use of a black mask between the phosphor and electrode has been shown to improve this figure up to 150:1. In each case an increase in luminous intensity of around 2x is required to compensate for the reduction in transmission/emission. A marked decrease in operating lifetime would result if this compensation were to be achieved through the increase in driving voltage. So such improvements must be made by increased performance from the phosphor materials. Such rigorous demands on phosphor efficiency could be offset if there were some means of prolonging the emission of light from any address element beyond that period for which the addressing voltage is applied, as is the case with TFT LCDs. Unfortunately, the only method for achieving this memory function with EL displays causes difficulties for grey scale control, which is a prerequisite of full VGA. Efforts are being made to overcome this limitation and include the integration of TFTs, or other active elements, and the use of frame rate control. TFT requirements for EL displays are not so restrictive as for TFT LCDs because there is no

need to make the TFT transparent, or to restrict the feature size, and thus the performance, so as not to interfere with light transmission. This is because the TFT, or similar device, can be formed on the rear substrate, behind the light emitting layer, in a position where it does not interfere optically with the image. An EL display element is also some 30% faster than even the latest low viscosity LCD cells, so the tolerances of any such 'Active Matrix' are inherently less critical for this application. In turn this should mean superior production yields.

Power consumption is presently another aspect of EL displays which needs to be improved in order to match that of similar LCDs. Currently figures for EL displays are in the region of 2x to 3x that of a comparable LCDs.

Other than improving the performance of phosphor materials one other area in which the potential for significant power savings exists is in the efficiency of the display drive schemes and driver IC. This accounts for almost 50% of the power consumption in a typical free format EL display. Drive schemes recently demonstrated, which employ energy recovery circuitry, have shown that the potential to reduce the power consumption to the level of comparable LCDs are achievable. Such developments, coupled to improvements in phosphor efficiency should realise a display that can match, or better, any comparable LCD in the near future.

It is apparent that significant development is required before EL can be considered as a practical alternative to other display technologies, except for certain niche markets. Annual increases in both sales and performance have reached the 40% mark. If this trend continues, EL technology could develop into the leading display technology, with superior performance in response speed, size and viewing characteristics over similar LCD products. This would appear to be a technology waiting for a breakthrough. If that breakthrough were to be forthcoming it would almost certainly result in a new revolution within the display industry.

2.6 Other Interesting Technologies

Amongst the variety of other technologies available, or already on the market, there are perhaps two which are worthy of address. Both are closely related to CRT technology.

2.6.1 Beam Matrix Displays

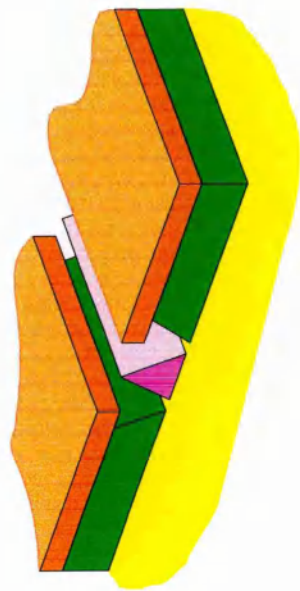
The first of these, beam matrix^{xx}, is a particularly recent development. The principle of operation is similar to that of the CRT and VFD, but it does away with the bulky electron gun and deflection system used by CRTs. Instead horizontal beam filaments produce the electrons whose path is then controlled by vertical beam electrodes on to a typical, but flat, CRT type screen. The electrode

arrangement treats each pixel as an independent display segment, as is the case with other flat panel electronic display technologies, allowing a greater degree of integration and compatibility. There is also no longer any need for the shadow mask required by CRTs. Matsushita have pioneered the development of this technology and produced a commercially available 21" diagonal screen device that is only 4" in depth. Still, it is only ever likely to appear as a stop-gap solution to the packaging problems caused by large CRT displays. It still represents a fairly bulky package, and the requirement for an evacuated chamber will require considerable thickness of glass materials, and more intricate electrode arrangement to accommodate large screen dimensions. Because this is such a new technology, developed by a single manufacturer, there is little evidence to support the notion that such a technique could be used to produce the size of display required by HDTV applications.

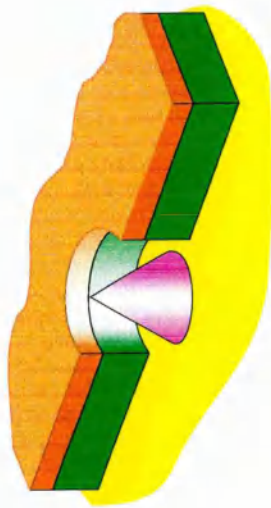
2.6.2 Field Emission Displays

Field emission displays (FEDs)^{xxi xxii} have been under investigation for some years. Indeed the theories behind Field emission arrays were first developed in the '50's as the solution to integrated electronics. This role was finally filled by solid-state electronics. Lifetime and brightness have both been insurmountable problems, however. Like a CRT and VFD they rely on the mechanism of focusing electrons on to a phosphor, being made up from a cathode, control grid and phosphor coated anode. In fact they are essentially "micro-machined" VFDs. Fig. (14) illustrates the various techniques under development in this area. The electron source in this case is formed from an array of micron-sized, cold cathodes just behind the phosphor pixels. Unlike both the CRT and VFD, the electron source requires no pre-heating before becoming an effective electron source - it is the high electric field around the extremity of the cathodes which draws off electrons. Several cathodes per pixel are possible allowing a large, but inexpensive, degree of redundancy. Excitation of the phosphor is possible with voltages in the region of 200V-1kV^{xxiii}, as opposed to the 10's of kV required by CRTs, owing to the much closer proximity of cathode to phosphor, demanding less energy to achieve sufficient current density to produce similar levels of light emission. Because the electrons are accelerated through the aperture in the addressing electrode there are no electrons absorbed as they are accelerated towards the phosphor. Additionally, because the structure of an FED is micro-machined from solid laminates it is possible in principle to manufacture rugged, durable displays with screen dimensions up to 1m x 1m diagonally, and beyond, with a thickness of only 2mm-3mm.

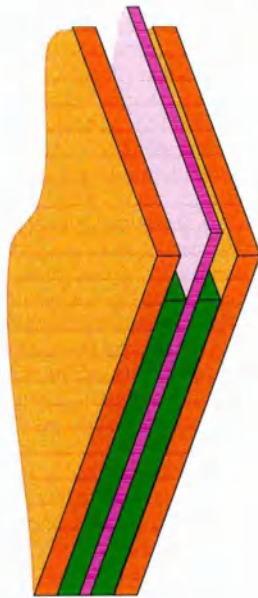
Problems with operational lifetime of phosphors, and more critically the cathode materials still persist, although significant developments have been made in both areas recently. Molybdenum, silicon and industrial diamond materials have each been developed as possible electron sources to the



Wedge Emitter



Point Emitter



Edge Emitter

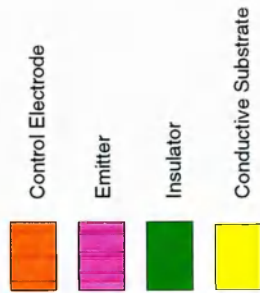


Fig. (14) Principal FED Architectures

These are the three principal emitter architectures being pursued by various commercial enterprises currently developing FED technology. By far the most prominent of these is the point emitter favoured by many of the leading groups.

verge of commercial practicability. Should these problems be overcome there is considerable potential for surpassing the low power characteristics that currently only full colour LCD can achieve.

3.0 Application in an Automotive Environment

The practical research element of this study is in the field of automotive instrumentation. The author was involved with this subject area at the time of embarkation on the course. The application of instrumentation technology into an automotive environment is demanding, and, in the case of FPD, principally unresolved and undeveloped. The commercial aspects for integrating flat panel technology into such a product it was judged would be especially challenging. Another aspect that was judged to make this subject of particular interest was the body of documentation associated with earlier attempts, and current research into FPD application in this area.

A significant amount of the work carried out in developing so called 'body electronics'^{*} for automobiles goes into the "man / machine interface". With the exception of small amounts of peripheral information, such as clocks, most vehicles today retain the traditional and familiar mechanical & electro-mechanical analogue meters. Fig.(15). The prolonged use of such traditional instrumentation comes despite a number of attempts over the past two decades, by various manufacturers, especially Japanese, to make greater use of contemporary electronic display technology.

Those attempts which have been made to replace traditional analogue metering in automotive dashboard clusters with digital, solid-state appliances have proven to be less than popular. Especially within Europe and the USA, with the result that analogue metering still persists. VFDs have been used extensively, in particular in Japan^{xxiv xxv}, and a number of novel approaches using hybrid arrangements have been developed^{xxvi}.

With the rising levels of high technology going into vehicles, and increased attention towards safety levels, come the need for increased levels of information. With this comes the need to present this information concisely and with the minimum distraction. In order to do this the information must be prioritised and presented accordingly. An example of how flat panel devices can successfully be integrated into such an application is the Fiat Tipo in some of the models, Fig.(16). Here, the designers paid attention to the limitations of flat panel technology and were wise enough not to try to mimic either the traditional style of meter, or the traditional style of dashboard layout. In fact they have designed a scheme somewhat different from any of the other previous attempts.

More advanced methods for achieving more effective and easily interrogated include the use of 'head-up displays' (HUD), which project the information onto an area of the windscreen, but require the use of complex optics to obtain a distant focal point. Also, growing demand for navigation

^{*} Grouping referring to all electronic components outside the engine compartment.

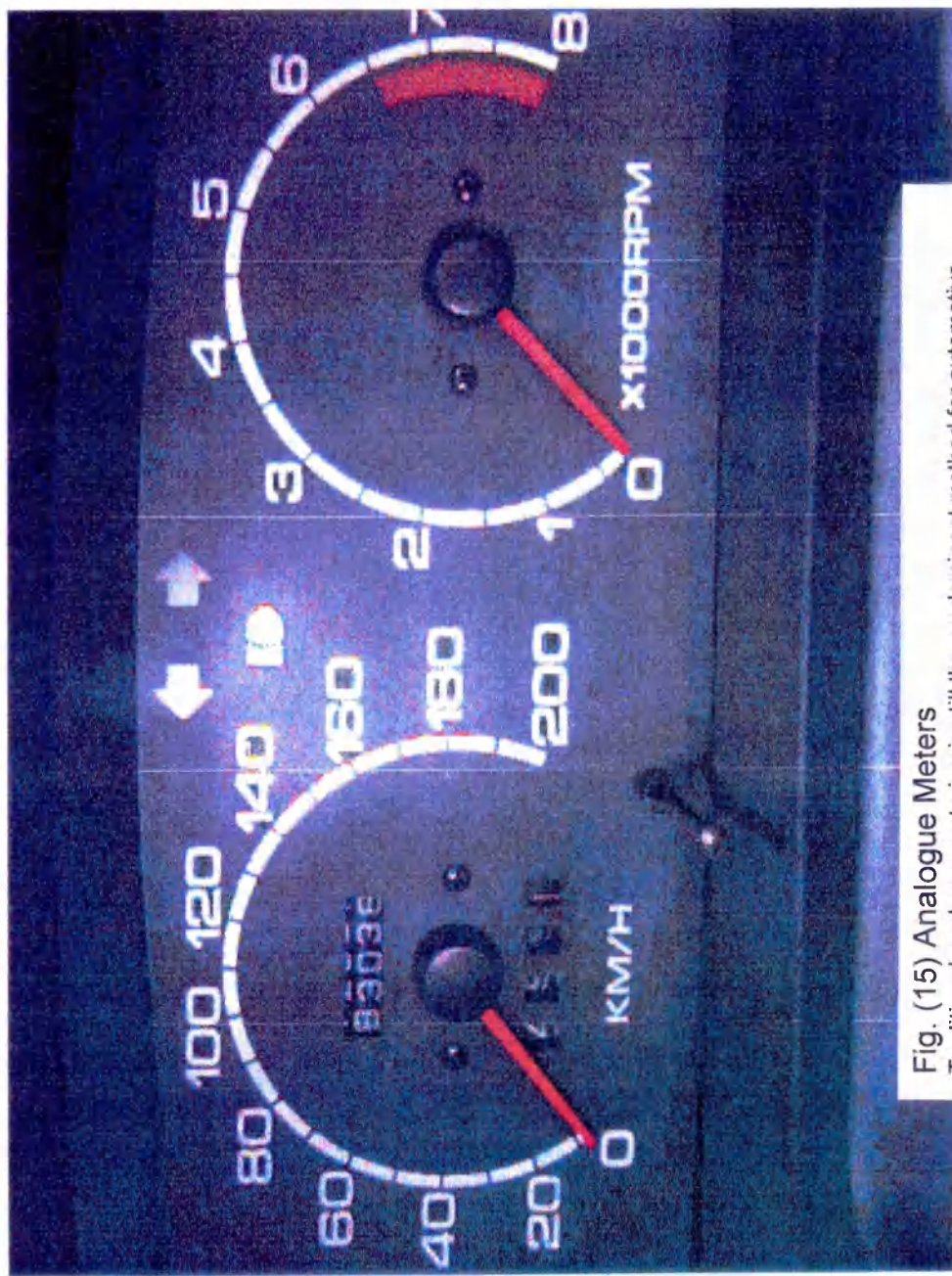


Fig. (15) Analogue Meters

Traditional analogue metering is still the predominant method for automotive instrumentation. Even the odometer is usually still a mechanical pinwheel.



Fig. (16) Fiat Tipo

The designers at Fiat made sure not to try and mimic more traditional analogue metering when integrating flat panel displays for this Tipo model.

information requires the use of a more complex display medium. For example, the reproduction of cartographic detail requires a re-configurable, multi-colour, high resolution display, Fig.(17). The integration of rear view video, or visibility enhancement features such as collision avoidance radar and night vision have a similar requirement.

Such applications are beyond the scope of this dissertation. Here a more specific, rationalised and practical investigation has been undertaken. This concerns the information currently provided by quality saloon cars, and ways in which this can best be presented in the form of a 'Driver Information and Warning Unit'.

This work is supported by documentation suggesting possible improvements offered by customisation and the likelihood of improvements through future developments. Regular reference will be made to existing attempts, and at least a paper work review of the viability of future developments in the area of HUD and GPS.* Fig.(18) illustrates one manufacturer's vision of the future for automotive instrumentation.

3.1 Model Specification

Ergonomic and aesthetic necessities were used to define technological requirements, identifying a set of objectives and essential characteristics to form the basis of a product specification. This specification is used as the substance of the design study discussed in this thesis. It is prudent to note that the criteria on which the specification has been based are those which have been found empirically, within the automotive industry, to be to be acceptable, as opposed to some scientifically derived optimum. For example: there is no legislated figure for the minimum luminosity of a dashboard instrument, the typical requirement is that it be clearly legible under a 1kW sunflood halogen lamp.

Initial study of the trends associated with automotive instrumentation revealed distinct problems with consumer acceptance of purely digital or analogue mimics of existing instrumentation. Various manufacturers, having produced such products in the past, found the consumers' perception of their product to be poor aesthetically and confusing. Such was the case when British Leyland introduced a fully electronic instrumentation pack in its Maestro model. Other examples include Jaguar (XJ40) and GM (MkII Astra GTE), each of which returned to a more traditional style of instrumentation after the first revision. In the case of the Maestro this happened a little earlier than would normally have been the case. In March 1993 Jamie Bodley-Scott, of Lucas BSE, stated that

* GPS - Global Positioning Satellite; a term commonly used when referring to navigation technology.



Fig. (17) Navigation
Full, or even multiple colour
can provide a useful aid to
map reproduction, as shown
here.



Fig. (18) Vision of the Future

One manufacturer's vision of how flat panel displays will impact on the cabins of future automobiles.

solid-state electronic meters “have not found their niche”^{xxvii}. With this in mind it was decided to develop a product model which would concentrate the plethora of ancillary instrumentation into a single module, which could at the same time be used to provide supplementary and support information and offer scope for future developments such as satellite navigation. Furthermore, it was decided that it should remain sympathetic to the existing style. In addition an investigation was to be made of the use of solid-state light sources to illuminate both the retained analogue metering and warning symbols, in an attempt to improve the module’s reliability and extend its serviceability. So as to confine the development to some realistic platform the model was engineered around the skeleton of a contemporary Jaguar instrument pack. More ironically, it was based around the instrumentation cluster which had replaced the original electronic instrumentation of the early models. After making a review of the proposed information content, the mechanical arrangement and available technology, a suitable unit was identified.

It must be emphasised that the intention was neither to develop an electronic interface to the automobile operating system, nor to engage on a radical styling exercise, but to test the feasibility of both the concept and the display components.

3.1.1

- **Display Format.** Optimisation of product performance and versatility requires a single “free-format” or “reconfigurable” display, as opposed to a customised design using a specific icon arrangement. The latter, it must be noted, would have been far beyond the resources of the research. It would also have been physically impractical to integrate. The primary reason for this was the quantity and variety of information it was intended to represent under the constraints of optimising the compactness and effectiveness of the design. For example, only a relatively small area of the total display window may be dedicated to any one individual icon, in the case of a customised configuration. Whereas, in the case of a free-format display the whole display area may, if necessary, be used to represent any single item, or group of items, and the format used to display such information in the optimum arrangement, rather than distributed across the viewing area. As a result the information can be classified by its original position in the design not necessarily its priority in the message. Adopting a free format also supported the ideal of developing a non-application specific display subsystem. With today’s trend towards producing “world marques”, that is globally marketed products^{xxviii}, this gives it the required intrinsic portability. It also supports the facility to update, or re-model, without re-developing any hardware^{xxix}. Whilst the optimum arrangement of information displayed on a free-format display may be compromised if more than one group / message is

demanding attention at any one time, it does allow those demands to be prioritised. Lower priority demands can be represented in small scale within a specific area of the display until higher priority demands have been dealt with. Any such information classified as a warning would be displayed supplementary to a regulatory ISO symbol warning system.

3.1.2

- **Technology Options.** The format of the model having been established, a 320x240 STN LCD, with cold-cathode fluorescent lamp (CCFL) backlight was chosen as the reconfigurable element (see appendix and table 2).

Consideration was made as to what future features it would be necessary to integrate in order to keep the unit up to date. This meant that full-colour, high resolution would be required if present themes for navigation systems were to be implemented. VFDs are not suitable, as they have neither the ability to offer high density full-colour, or high information content over any reasonable viewing area. Mechanically PDPs become bulky for small screen diagonals, as well as not being sufficiently well developed for full-colour performance. EL displays cannot offer full-colour at this time. Which leaves LCD as the only contender amongst the flat panel choices. However, a rigid set of operating criteria had to be faced in terms of contrast ratio, operating temperature and luminance^{xxx}, without consideration for which technology was being implemented. Table (1) provides a summary of the comparisons between the various technologies. A more thorough guide is contained in the appendix^{xxxi}

Problem	AC PDP	DC PDP	Beam Matrix	ACTFEL	DCPEL	PMLCD	AMLCD
Luminous Efficiency	✓	✓					
Matrix Addressing					✓	✓	
Uniformity				✓		✓	
Viewability (Indoor)						✓ ¹	✓ ¹
Viewability (Outdoor)	X	X	✓	✓	X		
Grey Scale	✓			✓		✓	
Multi-Colour	✓			✓	✓	✓ ¹	✓ ¹
Large Area				✓	✓		X
Driving Cost	X	X	✓	X	X		
Panel Cost	✓	✓	X	✓			✓

✓=Current Concern X=Probable Long Term Concern ✓¹= Unless Backlit

Table (1) - Summary of Comparisons Between Technologies

Electrical Characteristics:	
Driving Voltage	-20V
Operating Current	480 μ A
Overall Display Dimensions	108 (H) x 131 (W) x 5.5 (D)
Active Display Area	76.77 (H) x 102.37 (W)
Pixel Pitch	0.32
Pixel Size	0.29 (H) x 0.29 (W)
Resolution	320 (W) x 240 (H)
Multiplex Ratio	1:120*
Average Response @ 25°C	195mS
Contrast Ratio	37:1
Viewing Angle	+25° / -25° horizontal +20° / -30° vertical

* - Split Screen Addressing^W

Table (2) - DSTN LCD Specifications

Typical figures for LCDs were available from industry sources and the specifications for such an LCD are listed in table (2). These criteria, as well as economic aspects, could be satisfied by using a monochrome super-twisted nematic liquid crystal display (STN LCD) of 320 x 240 pixel resolution. This ruled out potential problems of repetitive pattern etching associated with emissive technologies, where analogue reproduction can lead to certain active areas being addressed more often than others leading to uneven ageing. It also showed a distinct advantage in terms of cost and availability. There remained a concern as to the ability of standard STN technology to perform satisfactorily over the extreme environmental range, whilst continuing to exhibit adequate contrast, viewing cone, luminance and speed, as the criteria laid down in the specification represented the absolute limits of this technology at the time. It may indeed be suggested that those figures themselves were a compromise in order to facilitate the use of LCD technology in the first place, as they are, as stated, very much those characteristics found to be acceptable, rather than ideal. The use of DSTN would have improved the appearance as well as the performance, enhancing both viewing angle and contrast ratio, in addition to permitting true black and white reproduction. But this technology is not readily available as an 'off the shelf' item, as is the case with current AMLCD technology, which would have been the preferred option. The use of standard product did enable the investigation of the concept, and relevant information on both DSTN and AMLCD was available for correlation. In the event, the 320 x 240 format chosen offered a relatively high resolution of graphics within the 4" to 5" available from the Jaguar pack. An added advantage is that it represents 1/4 VGA standard. This means a potential

^W Split Screen Addressing requires the screen be addressed as two separate halves. This is not ideal as the fringe field effects between the two halves of the display cause the boundary between them to be made visible by a loss of contrast. It also makes additional demands on the alignment tolerances within the manufacturing stages.

advantage when compiling the software with which the information intended for display was to be configured. It had been hoped to complete the investigation by integrating a similar format AC-EL display for purposes of comparison, but the lack of commercial support on this occasion prevented this.

3.1.3

- **Display Illumination.** A cold cathode fluorescent lamp (CCFL) backlight was used to backlight the STN LCD because of its very slim, compact profile, bright white, even distribution of light and cool operating temperature. In addition CCFL offers considerable improvements over incandescent lamps in terms of 2 to 3 times the lifetime, and colour balance. One drawback is its need for additional DC/AC voltage conversion circuitry to generate the required discharge voltage - a not insignificant addition relative to product reliability. Also, in order to maximise the efficiency of these lamps such “inverters” operate at frequencies in the range 30kHz to 85kHz typically, and hence can be a source of troublesome amounts of electrical, and audible noise. The European Directive on EMC (electromagnetic compliance) legislates strict control over the levels of electromagnetic emission and susceptibility of all products. Often in cases where the levels of luminance need to be optimised hot cathode fluorescent lamps (HCFL) are used. Generally this is true in the case of full colour STN displays, where the efficiency of the colour filters is a further limiting factor. However, in such an environment as the automobile instrumentation pack, where high levels of incident light may be present, the use of HCFL may again prove advantageous. Disadvantages are a loss in active lifetime, significantly higher current consumption and a slightly higher operating temperature. Table (3) illustrates typical operating characteristics for CCFL and HCFL. HCFL also shows an advantage in terms of low temperature starting. CCFL would be hard pushed to start at temperatures below -20°C.

Parameter	CCFL	HCFL
Lamp Operating Voltage	460V	120V
Lamp Operating Current	6mA	140mA
Lamp Starting Voltage	1000V	600V
Filament Voltage	N/A	4.2V
Filament Current	N/A	320mA
Luminance	12000cd/m2	25000d/m2
Lifetime	20000hrs	10000hrs

Table (3) - Comparison Between Cold and Hot Cathode Lamps

3.1.4

- **ISO Symbol Illumination.** In the past ISO symbols had almost exclusively been passive icon designs backlit by incandescent lamps, though one or two notable attempts had been made to integrate

such information into a single multi-purpose display. Jaguar had, for example, in the early XJ40 series, used a low resolution, monochrome, free-format VFD matrix, with an LED illuminated warning ring around the periphery to indicate severity. This proved to be an effective method of warning communication, but fell foul of legislators on two counts. Firstly the ISO symbols themselves were not represented by the appropriate colour, and secondly there was a concern that a single catastrophic fault with the main display would knock out the entire warning system. Another similar example was the use of bi-colour LED devices to backlight an LCD free-format matrix in Rolls-Royces Silver Spur trip computers. Whilst in this case the ISO symbols are represented by the appropriate colour, it still suffered from the same catastrophic failure scenario as the Jaguar design. In practice it also suffered from appalling legibility owing to the highly sensitive nature of the negative image of LCDs, in particular to light wavelength. By developing an ISO warning system along conventional lines these limitations are eliminated. In which case only two practical options existed for backlighting both analogue metering and warning annunciators, traditional incandescent lamps, or light emitting diodes (LEDs). The intention was to improve on what was already commercially available, in terms of reliability, serviceability and manufacture. The LEDs option was the only route that suggested any potential for achieving a radical improvement in overall performance. LEDs exhibit superior performance to incandescents in several areas^{xxxxi}. The most prodigious benefit is the huge dividend in terms of lifetime and reliability. They have the potential to outlast incandescents by an order of 100 - 250 times, and tend to fail gradually over a prolonged period as opposed to catastrophically. In addition they have a capacity to withstand repetitive switching in excess of incandescents, by a similar order of magnitude. In terms of response speed and operating temperature LEDs also possess a significant advantage over this competition. This is of major concern when considering the demands on manufacturers to optimise compartment space and improve the weight efficiency of their vehicles. LEDs are more mechanically robust than almost any other technology. They can be easily integrated into the instrumentation system at a board level, improving the testability, and hence the reliability of the overall product. The Achilles' heel of LEDs is their relatively limited range of available colours, limited spectral output and higher relative cost.

3.1.5

- **Information Configuration.** With the hardware specification fixed it was necessary to create an effective format for the screen information that would demonstrate the positive potential of the model. The purpose of this work was not to evolve some new style, or fashion. The pertinent information had to be consolidated into associate groups, the graphics kept simple, clear and concise, making use,

where appropriate, of regulatory ISO symbology and existing conventions with respect to manufacturers' layouts, representing all the various fields of information in a way that would explore the core needs of any information system, but also access a generically portable product. This approach was explicitly intended to demonstrate the versatility of the developed model, and prove the concept, whilst by default raising issues pertinent to further development.

4.0 Design Solution

Having formulated specifications for a design the next step was to optimise their implementation. This required the development of a physical layout that optimised the effectiveness of the components and which also satisfied the objectives on which the study was founded: integration of a concept into a practical environment, and its objective analysis were the goals^{xxxxiii}.

4.1 Instrumentation Layout

To a large extent many of the formulations were qualified by the requisite limitations of the Jaguar pack. For instance, the dimensions of the 320 x 240 pixel display closely replicated those of the principal analogue metering it was intended to replace. Fig.(19). A free-format facilitates the reproduction of all the required information in some form or other. Nevertheless, this would not have optimised the effectiveness of the overall unit. It was necessary to retain the primary information on a permanent basis needing no selection, whilst also retaining the original character of the instrumentation by adopting a conventional layout, incorporating the original principal analogue meter, namely the speedometer. In a typical instrument pack format, incorporating speedometer and tachometer (or clock), the main metering is situated centrally to the additional metering situated around the periphery, as with the unit fitted to the model released under the Daimler marque and illustrated in Fig. (20). The original instrument pack used within the Jaguar arrayed the status indicators in several indistinct clusters, also around the periphery. A key objective of the design solution was to create a format that could be read with a minimum of interrogation. So whilst a symmetrical layout for the principal metering was retained, the ISO warning annunciators were centrally grouped by function. Those of the highest priority (Red) were contained within a single matrix, along with those used to indicate the most commonly encountered attributes, head / tail lamp and direction indicator status, in distinct groups between the principal instruments. Those indicators assigned to information of an intermediate priority (Amber) were arranged as a single line either side of the central cluster, and below the principal instruments. This configuration effectively separated and underwrote the combination of analogue speedometer and LCD. Fig.(21). In addition to being a more effective combination this was a far simpler arrangement to engineer than the original design. The close grouping of the warning annunciators would not have been possible if incandescent lamps had been used in preference to LED owing to the potential for excessive heat generation by the hot filaments of incandescent lamps. This is a problem that compromises many current designs. Because the risk of several indicators being active

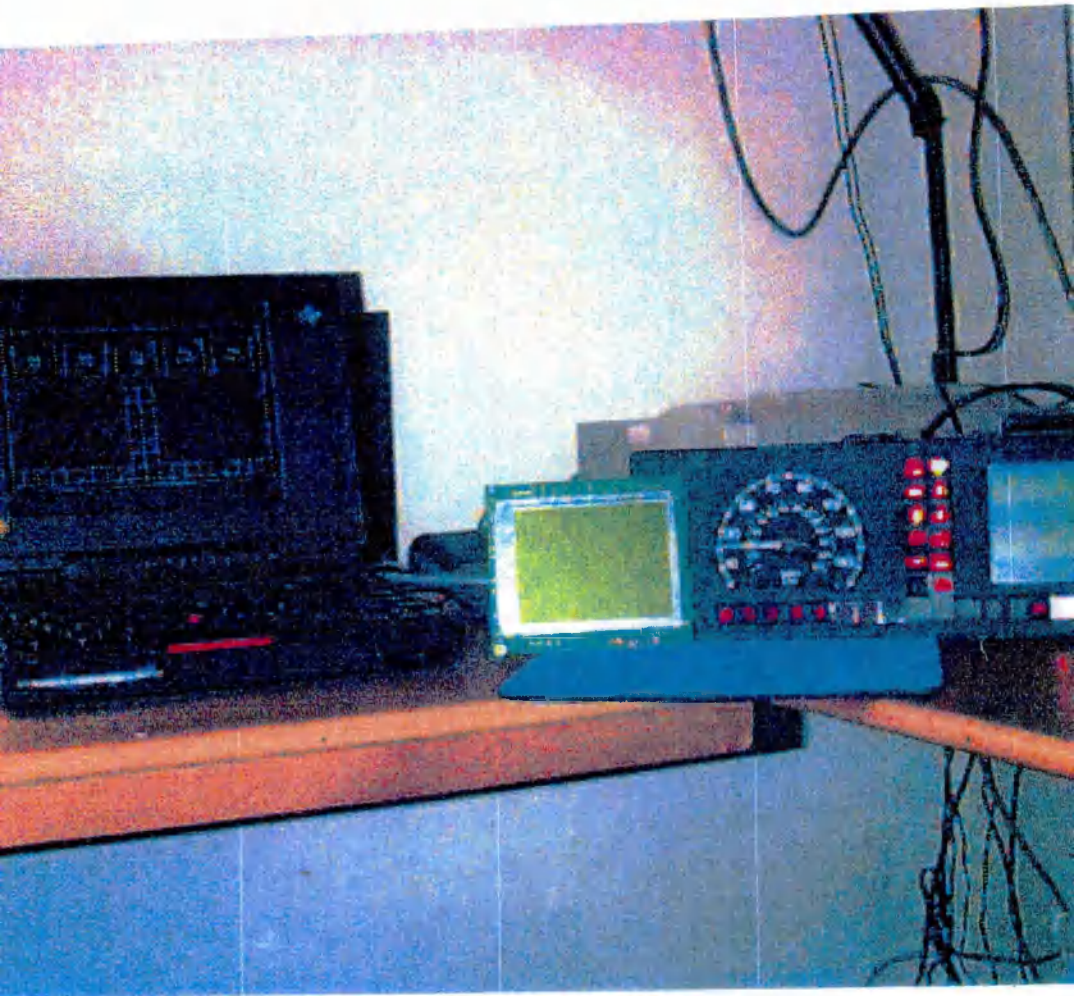


Fig. (19) Free Format Display vs Analogue Meter

One of the 320x240 resolution free format displays alongside the conventional analogue meter showing the size compatibility. Also shown is the notebook PC running the application software developed to run the final design.

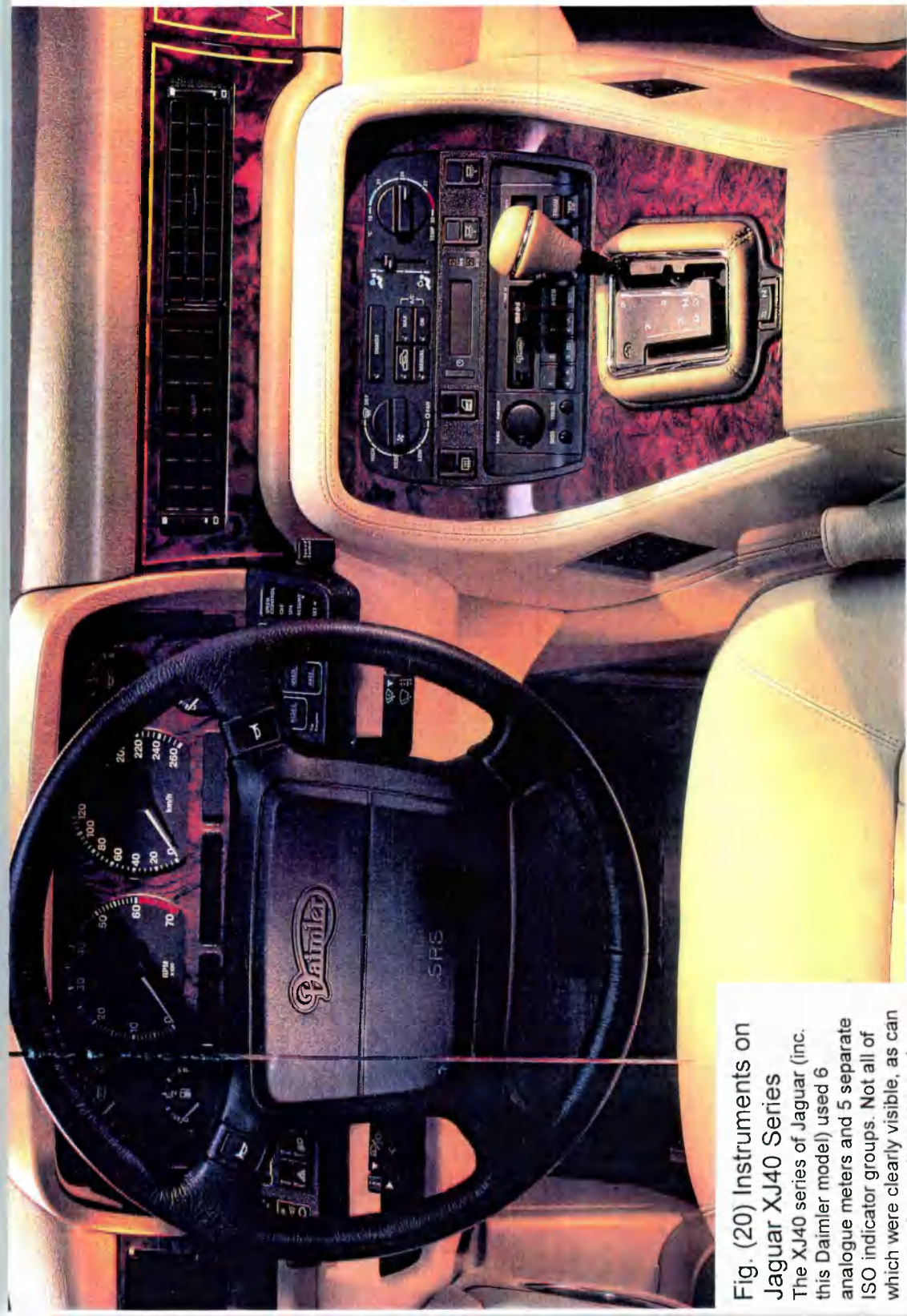


Fig. (20) Instruments on Jaguar XJ40 Series
The XJ40 series of Jaguar (inc. this Daimler model) used 6 analogue meters and 5 separate ISO indicator groups. Not all of which were clearly visible, as can be seen from this photograph.

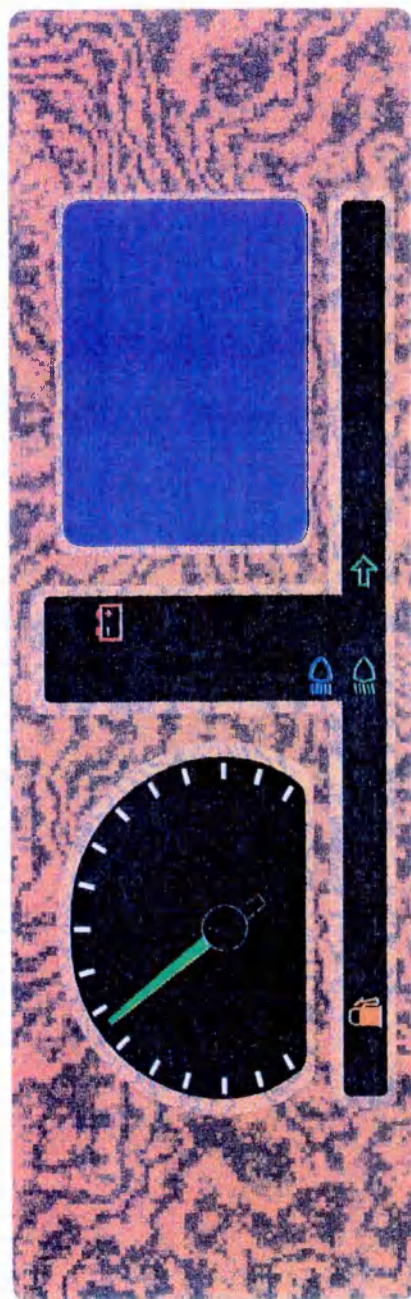


Fig. (21) Schematic of Facia Layout Design for Model
This schematic was developed based on the original instrumentation package dimensions. It clearly illustrates how it was possible to package all of the information more compactly. As the final model did not include a natural veneer finish it also gives an idea of how a commercial arrangement might appear.

simultaneously for sufficient time to cause a problem is low, this problem is usually disregarded, or the indicators are more widely spread than they need otherwise be.

4.2 Firmware

Having established the configuration of the instrumentation a suitable means of operating the LCD was required. There are numerous devices on the market designed to provide an interface to displays of 320 x 240 pixel format. However, all are commonly only available in Surface Mount Technology (SMT) packaging, which means that bread boarding was impractical unless expensive leaded IC carriers were used. The aspect of component packaging was an overriding concern throughout the design stage. As the necessary facilities were available, a single-sided PCB was manufactured which could accommodate all the necessary hardware for communicating to the free-format display.

The choice of display controller was an arbitrary one, each manufacturer's devices being similar in configuration and protocol. Two devices were initially considered, the OKI MSM6255 and the Seiko Epson SED1330. The former device has a relatively simple operating protocol, but could offer only a graphic interface. The SED1330 on the other hand offered the ability to address the display in both graphic and character mode. It was also available in a range of products which included DC/DC converters* for generating the LCD driving voltage, and display RAM. An early attempt was made to use the OKI MSM6255 on the custom designed, single-sided PCB with a micro-controller interface in the form of an Intel 8749, and a 512K EPROM to store the screen information; see Fig.(22). Though successful in a stand alone format it was difficult to devise an adequate interface to a PC using this micro-controller because of hardware restrictions, and the etching of a PCB with the necessary pad pitch to mount the SMT packages proved to be particularly troublesome. This limited the degree of interaction with the design, and meant that the prototype was extremely fragile. By using a combination of standard products to overcome these limitations, and customised product where necessary, the problems of wasted time spent resurrecting un-reliable material was avoided. A parallel port buffer assembly was used to allow the PC to interface directly to an SED1330 and the ISO symbol interface. The LCD controller was part of another sub-assembly which had a DC/DC converter built in capable of providing the 24V LCD drive voltage, along with the necessary display RAM. A further sub-assembly was manufactured using single sided PCB again on which to mount the LED array, and associated driver IC for ISO symbol illumination. This was fabricated by a professional PCB manufacturer.

* DC/DC converter is a circuit/device which converts a DC voltage to some other DC voltage level.

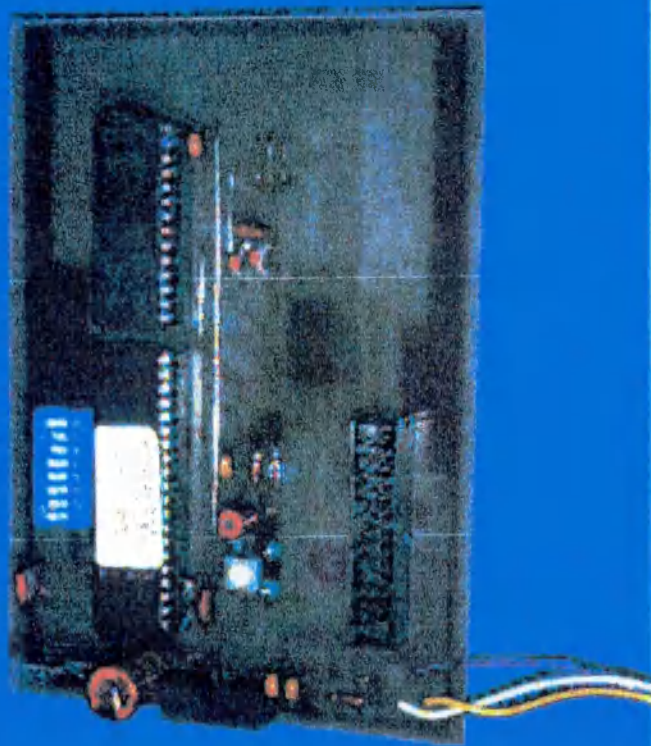


Fig. (22) Oki MSM6255 Display Controller Module

Fabricated using simple single sided PCB materials this shows the original display controller module using an Oki MSM6255 IC. The display controller is a SMD component assembled to the other side of the PCB. The two ICs visible are a 512K EPROM and an Intel 8749 MCU.

Each of the display controller's specifications are both lengthy and detailed, so reference must be made to the manufacturer's data. A brief outline for each of the devices used is contained in the appendix, and a block diagram of each device is given in Fig.(23). In each case a display controller needs to be initialised, to operate in the desired format. Each device is programmable so as to permit control of a range of display formats (640x200 - OKI MSM6255, 512x128 SED1330, and any sub-group thereof). A PC based software routine was written using 'C' language for controlling both the LCD and ISO symbol illuminators with a simple VDU graphic interface. This also meant that all the screen information could be stored, and accessed, via the computer's hard disk. The facility to do this was particularly useful as the screen information and layout was constructed using a software product developed specifically for demonstrating the operation of free-format displays, up to VGA format, from a PC. This graphic interface allowed the user visually to construct the desired layout before converting it into an Intel HEX format which could be accessed from files used for the screen memory. Unfortunately, it did not have the facility to provide any form of animation, as would have been desired to mimic the operation of say the tachometer. An attempt to overcome this minor drawback was made within the control routine by writing several different sets of screen information in sequence to mimic the rise and fall of the tachometer. This worked well, though in a practical application it would be achieved by updating only the specific area of system RAM in real time.

As with any device of this complexity the setting up, or initialisation, of the graphic display controller was critical. Every aspect of the device's features had to be reviewed in order to achieve an error free message on the display. The routine by which the controller was initialised is contained at the beginning of the 'C' routine developed to control the unit. A copy of this routine can be found in the appendix.

4.3 Information Format

In general the information designed into each of the screen layouts was a replica of or additional to that in the existing Jaguar instrumentation pack. A study of current modes and contemporary consumer research was made in order to support the selection of this information, and to ratify the order of priority attached to it.

When constructing the layout of each of the screens, attempts were made to replicate, where appropriate, the configuration of existing instrumentation. Where this was either not possible, or inappropriate, as in the case of the gauge representation, the layout was kept as simple and clear as possible. This philosophy was adopted when deciding the content of each screen. In hindsight it would



The Seiko device was ultimately chosen as the control engine to drive the final design, owing in part to its greater versatility. This device has subsequently been replaced by the SED1335.

perhaps have been desirable to have supplemented each graphical image with numeric information. Whilst it would have been possible to dedicate the whole of one screen to a particular subject at a time, for say the reproduction of tachometer information, it was felt that approach was not representative of the goal of the investigation. A more flexible and well developed software product would enable the bit generation of individual information into a single screen format when desired. This would also then allow the additional numeric information to be present. But that sort of development will be discussed as part of the review of further development potential in a later chapter. Either of these 'distractions' would anyway have radically extended the time allocated to this particular section of the study. In any case each screen contained information which it was felt related to each other. Fig.(24) shows the three screen formats which were developed. It should be realised that in spite of the software tools available it took many hours of work to construct each screen format. These software tools were basic graphic-to-Intel HEX translation programs and had none of the advanced layout tools of advanced drawing packages. Equally it must be understood that the scope for information display using such an arrangement is largely software related. The ethos behind the concept was to illustrate its inherent flexibility and versatility. By using a modicum of imagination it should be easy to realise the potential for displaying diagnostics, navigation aids or even personal communication facilities, a 'super pager', for example, with the capacity for electronic mail.

4.4 ISO Symbol Implementation

Fig.(25) illustrates how well warning information can be represented using the free-format screen. Because of the various international, and national, regulatory restrictions it was necessary to implement the ISO warning system as an array of dedicated indicators, represented by accepted icon descriptions and colour. A single sided PCB was designed using FastCAD and fabricated by Mhotrak Ltd. This permitted the mounting of the whole backlighting array, along with driver electronics and current limiting resistors, into a single unit. Usually each of the LED groups would have been protected by an in-line signal diode to prevent against reverse voltage. These were not required for prototyping.

Each icon was back-lit by a pair of LED devices. In all but two cases the packages used were miniature SMT devices. In the other two cases 3mm diameter radial, through hole mounted devices were used. In one case this was to back-light a red warning icon using a new high brightness, wide angle package to see if there was any reasonable benefit over the SMT devices. The second application for the 3mm radial type was to back light the blue 'main beam' icon. Blue LEDs are still relatively

Fig. (24) Screen Formats for Free Format Display

A free format display provides a high degree of versatility, allowing information of a varied nature to be centered on a common instrument. The three photographs shown illustrate how conventional cabin information can be easily represented using this arrangement. Here it is illustrated how vital status, environmental and entertainment information can be 'paged' to fit the free format display arrangement.

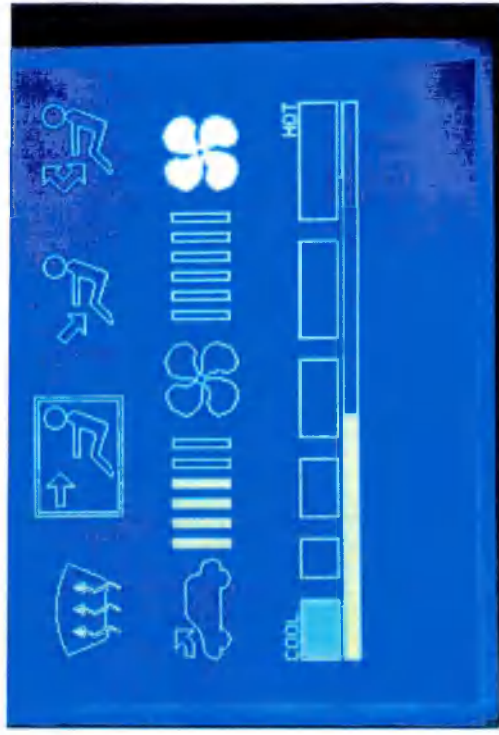
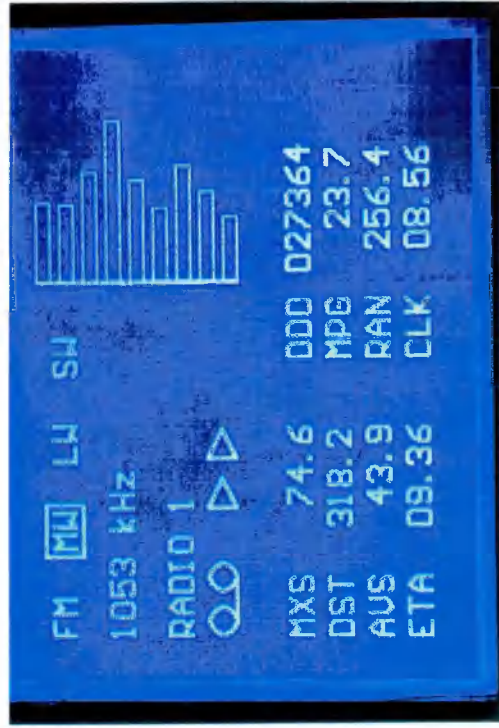
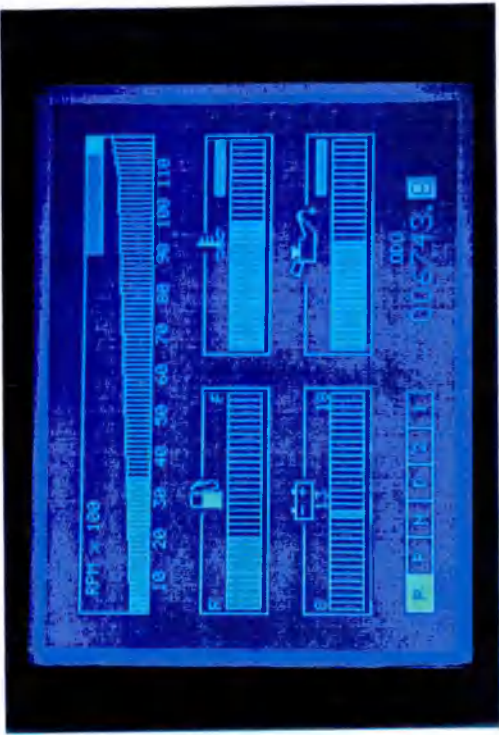
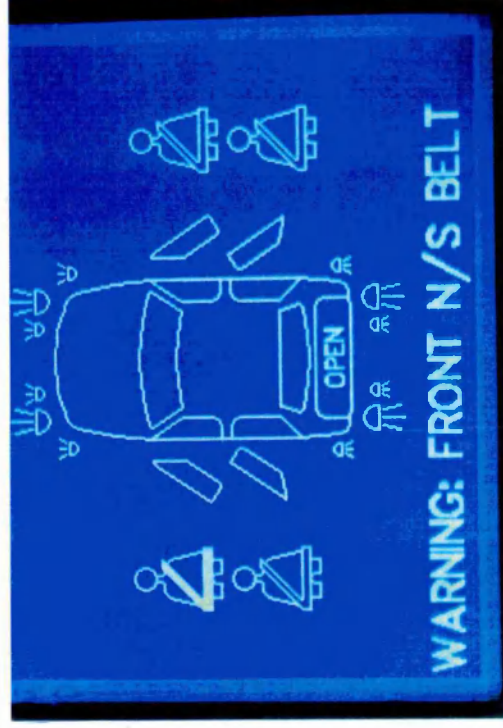


Fig. (25) Supplementary Warning Information

The free format display can easily be configured to provide supplementary, and more comprehensive warning information to the statutory ISO warning indicators. This view illustrates how secondary warning information such as seatbelts, doors and exterior lamps can be flagged.



scarce in the market and no suitable SMT device could be found. The use of the word 'suitable' is relative as blue LEDs offer only a very poor performance in any case. The miniature nature of the SMT packages had the advantage of allowing a very compact light chamber to be constructed. From experience, and the study of other commercial designs a chamber depth of 8 - 10 mm was thought to be ideal. In the case of radial type LED packages a chamber depth of 20 mm would be typical.

Unlike incandescent lamps, LEDs are not available in a range of power ratings which define their brightness. So to prove the feasibility of using LED it was necessary to optimise the level of light projected towards the icon window. The PCB surface around the LED was coated white. Other precautions taken to make the most of the available light were to use a plastic material with a high coefficient of reflectivity (Bayer 10244, 99.98%) with a bevelled aperture, and an LED type with a light projecting lens, Fig.(26b). The tooling used when producing the reflector component limited the fashion of the chamber to an 8° bevel. An elliptically optimised profile would have been an advantage, though the degree of benefit would have been limited, and it was not considered that the lack of such a facility would mean the difference between proving or disproving the design's viability.

Existing films were used to represent the necessary icons purely as a matter of convenience. These had the disadvantage of already having filters of a particular colour co-ordination for their original design. This affected the final performance of the annunciators. However, they also featured the necessary diffusion characteristics to give a good balance of light across the symbol, correct levels of neutral density* and of course representative icon designs that would permit a degree of correlation between existing products. The results indeed speak for themselves. In addition a single LED 5mm lamp was fitted to the aperture of the Analogue meter pointer to determine the effectiveness of using LEDs to backlight whole areas and individual elements of the conventional instrumentation, Fig (27).

4.5 Fabrication

Finally, it should be explained that the LCD module used was primarily designed to be operated with its associated backlight, being optimised in the transmissive mode. It, therefore, performed better in lower ambient light levels. By definition it therefore performed relatively poorly in conditions of high ambient light, not being optimised for operation in a reflective mode. All displays of a non-reflective nature perform less satisfactorily under such conditions - exhibiting "washout"†. In an attempt to combat the effects of strong incident light which could be expected in such an

* Neutral Density refers to the ability to minimise ambient reflection without inhibiting transmission.

† "Washout" is the term which refers to the loss of legibility due to excessive incident light.



Fig. (26a) ISO Warning Indicators

These ISO warning indicators used commercial graphics from a variety of vehicles, including the original Jaguar design. The performance was in some cases inhibited by the colour filter used on these graphics, but the final indicator arrangement is well illustrated here.

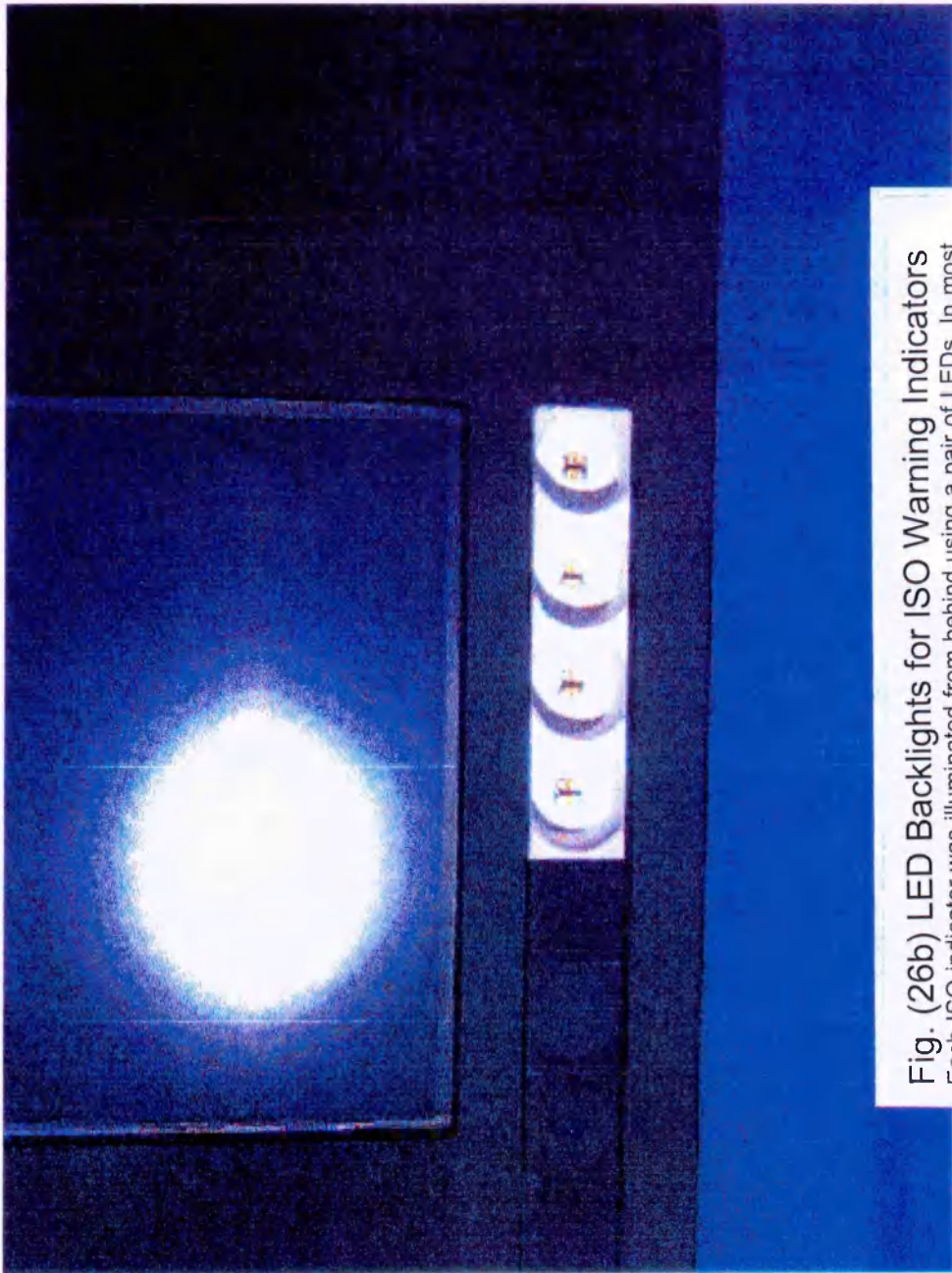


Fig. (26b) LED Backlights for ISO Warning Indicators
Each ISO indicator was illuminated from behind using a pair of LEDs. In most cases SMD type LEDs were used. These were assembled onto a white surfaced PCB with a high reflectivity white bezel surrounding them. The ISO graphics could then be stuck over the top of each aperture.

Fig. (27) LED Light Source for Analogue Meter Illumination

The green LED in this photograph was used to illuminate the pointer of the analogue meter on the final assembly. Whilst it worked to a degree, this shot shows that a great deal of light is lost to the surrounding area. Although LEDs are relatively efficient light sources they are still limited in the amount of light they can generate. Care, therefore, needs to be taken to optimise the distribution of their output.



environment a "Light Control Film"TM filter was fitted across the display aperture. Full details of this product are contained within the appendix. It has the effect of absorbing light of one polarisation incident along a particular axis which is determined by its orientation. As the majority of applications would be within a cabin which had a permanent roof it was determined to try to inhibit the effects of strong incident light from either side. This meant orienting the filter with its laminations running perpendicular to normal. This actually had the effect of reducing washout and improving contrast, especially in the area of ISO warning symbols, where the nature of the surface diffusion films lead to a slight loss of contrast. Unfortunately, there was insufficient material to fit to the whole unit so in the model only the LCD aperture was covered.

A great improvement in the instrument's resistance to washout from strong ambient light in the horizontal plane was noticed, but with two major drawbacks. First, visibility is inherently limited from either side of the display, as the light emerging from the display is also absorbed along the horizontal plane. This means that it is not easily legible from the passenger seat, an important feature when using the filter material in such applications as remote teller machines, but a problem when incorporating entertainment features such as radio tuning, etc., into the automobile instrumentation pack. It is also undesirable when setting cabin conditions or enquiring about trip information. Secondly, the filter also has a retarding effect on the performance of the LCD backlight.

The instrumentation arrangement was assembled onto a 5mm sheet of transparent perspex to allow easy inspection. By using suitable mounting pillars it was possible to arrange each individual component at the correct height to appear flush with the fascia panel. The fascia panel itself was machined from 3mm perspex with the same footprint as that of the original unit. The correct instrument apertures were routed out professionally, and the surface finished with a non-reflective black automotive specification paint. One aspect it was not possible to replicate was the mock veneer finish of the original unit.

TMLight Control Film is a product of 3M.

5.0 Analysis, Discussion of System and Conclusions

Previous chapters have described the specification and development of an automotive instrument pack along basically conventional lines, using facts and figures gathered from industry sources. The extent to which the solution succeeded in achieving set goals, and the extent to which the solution succeeded in enhancing automotive instrumentation must be analysed in order to determine the validity of the work.

To a large degree the success of the design is subjective. It can only be said to be successful if people like to use it and feel comfortable with it. The components used in automotive environments are rarely standard, or available 'off the shelf'. As in this case. It was necessary to rely on materials that were readily available to prove the conceptual validity of the developed model. Consequently, it would have been irrelevant to approach the analysis of the finished model by attempting to evaluate the performance in relation to a contemporary automotive environmental specification. Nor could it have been claimed that the model had been constructed using certified manufacturing processes. So the underlying reliability of the finished item could in no way be guaranteed, or realistically quantified. On the other hand, all this did not prevent relevant third parties, involved in automotive instrumentation development, from being invited to review the modeling principles. To what degree did industry experts agree with the relevance of the modeling concept?

When conducting this survey the model was only demonstrated, and no attempt was made to lead reviewers to analyse the model from any particular standpoint. Overall the response was extremely positive. Adopting an inherently portable concept was seen to be a key issue facing the instrumentation industry. The use of free-format displays, specifically LCDs, was seen as offering the greatest immediate potential for realising inherent portability, whilst also enabling the integration of higher levels of information content. Doubts were raised over the commercial feasibility of being able to use such a high resolution display format at the time. But it must also be realised that, since these opinions were first sought, the average cost of standard 1/4 VGA monochrome LCDs has more than halved. It was also suggested that much of the information being reproduced would also have to be clearly visible from elsewhere in the cabin. Information such as climate status and controls, and entertainment features. So possibly making use of two lower resolution displays (240x160 or 160x128 perhaps), with one mounted more centrally, would prove an effective adaptation. Certainly it was reported that the supplementary warning diagnosis was a significant advance, and that the model made contributions to evolution away from purely conventional instrumentation. The use of LEDs to backlight the ISO

indicators was strongly endorsed. As was the move away from more traditional packaging formats for their integration. Indeed it was felt that with a relatively little improvement in the commercial availability of LEDs for automotive applications, that they would begin a widespread move to adopt them universally for this use. Finally, there remained a level of scepticism regarding the suitability, over the short term, of CCFL backlighting for automotive instrumentation. Currently there are doubts as to whether CCFL can operate reliably over extended temperature ranges. HCFL was accepted as a possible alternative, but with reservation regarding proven lifetime.

This at least is a summary of the feedback received from demonstrating the model. With this information in mind an objective defence of the finished product is given here. Fig. (24) shows the various screen formats designed into the model, and indicates the versatility of the design. Whether, or not, any individual is happy with the screen format is irrelevant as not everyone likes to drive the same car. The model shows what can be achieved. Because the model had been designed with an open format the same operating system and firmware can be used for a whole range of applications by adapting only small amounts of the software content. The hardware package may have to be redesigned in each case, but the architecture is common, as are the majority of the component parts. So in terms of achieving a design that is generically adaptive the study was successful. It may be that the negative blue STN LCD is better replaced by a black and white DSTN. This would be less obtrusive, and perform better over the desired temperature range.

As previously suggested, a format other than full 1/4 VGA may be preferred, but there remain significant advantages to adopting a common architecture and open format instrumentation that have been realised by this model.

Regardless of the situation of the free format display the benefits of a common operating system, with common components have been proven. It may be that a fully traditional instrument arrangement is preferred, with the free format display mounted more centrally within the overall fascia. This would permit access to all the information from other situations than the driver's seat. This is particularly important because of the entertainment facilities integrated into the scheme. This would avoid many of the problems associated with electronic instruments of the past.

Minimising the likelihood of confusion must be a primary concern. People don't always drive the same car. They often change the marque and model they drive every one, or two years. Familiarity with instrumentation is an important aspect of safety. The switch to more friendly, effective instrumentation must be a gradual one, which takes account of the changing demands placed on them. As this report was being completed BMW announced a similar scheme as an option in its top of the

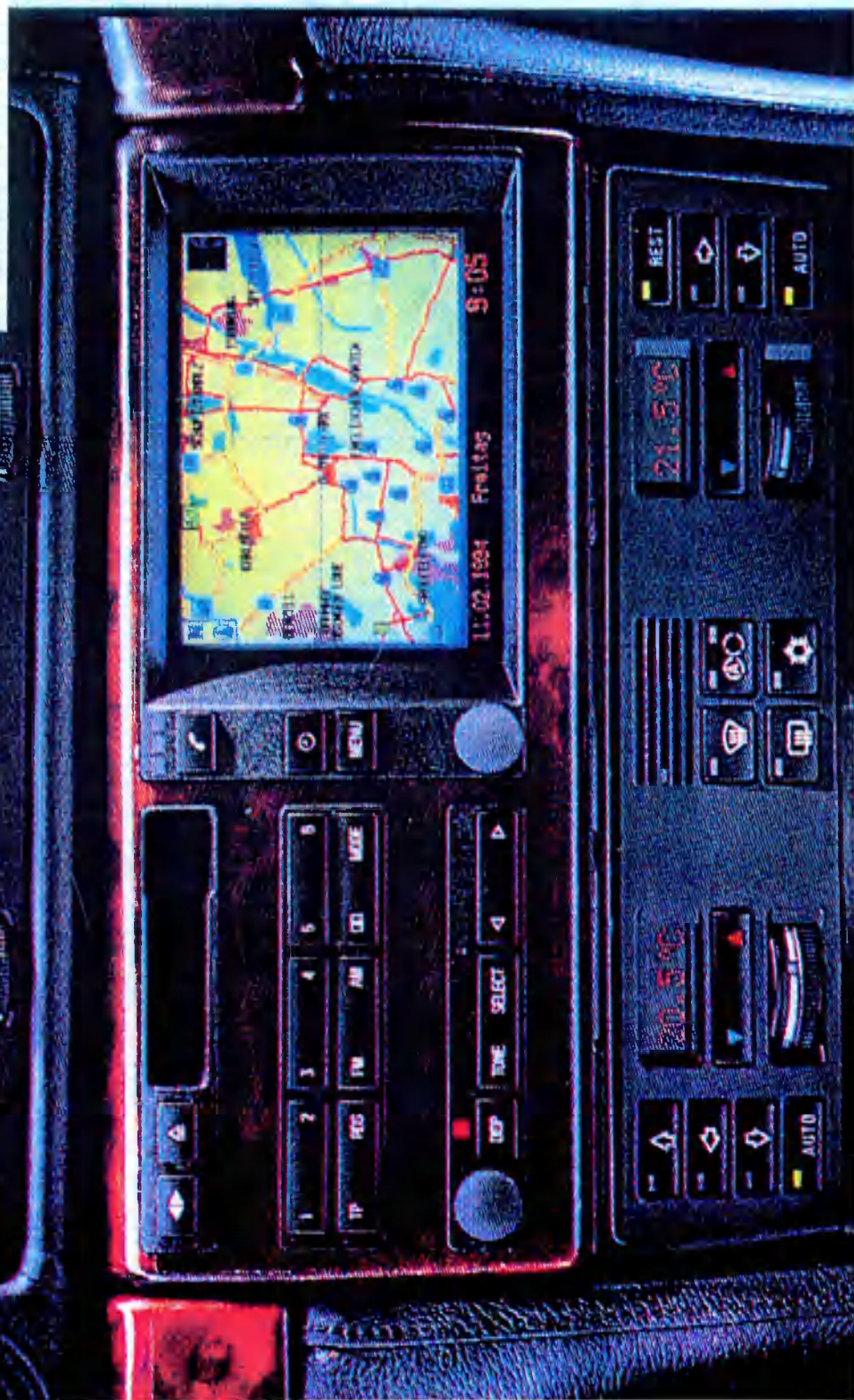
range '7 series', Fig. (28), offering a small, 1/4 VGA, full colour TFT LCD display, capable of providing TV, as an option mounted centrally within the cockpit fascia. Being an option, and using TFT LCD, it has not been conceived with the same objectives of achieving a common system as has been used here. It does highlight the common approach being sought by manufacturers within the automotive field.

In some respects the LCD module used satisfied the specifications listed in Table (1). It was legible under most circumstances, though the contrast ratio (listed by the manufacturer as between 3:1 and 4:1) was well below that specified. It must be noted that the specification was based upon a screen that used 'split screen' addressing, which effectively halves the multiplex ratio. Even with such a scheme it is difficult to see how a contrast ratio of more than 20:1 could be achieved. However, at the time of writing this chapter market figures from Japan and Korea suggest that the list price of TFT LCDs has fallen significantly. The coming introduction of next generation TFT production facilities will certainly see the further reduction in price of such devices, as yields are significantly improved, and traditional markets in portable computing become saturated.

Fig (25) illustrates the effectiveness of using the free format display to supplement the traditional ISO warning indicators. An ISO warning indicator may inform the occupants of the vehicle that a seat belt is not fastened, or a door is not closed properly, but it does not demonstrate the information with the same accuracy possible here. The ISO symbols themselves are shown in Fig (26a). The red LED worked superbly, as did the amber. The blue LED is inadequate to perform the job usefully, though, if the price became more acceptable, only a little improvement would be required to rectify the deficiency. After all, the blue device is only used for highlighting the full beam indicator, and full-beam is unlikely to be required in high ambient lighting conditions. Those indicators employing green LED exhibited marginal performance. Much of what was lacking in the performance could probably have been redressed by using more suitable filtering techniques and optimising the design of the light box. Again, it is purely subjective, but with a minimum of engineering effort the LED has been proved to be a credible alternative to incandescent lamps. Fig. (27) illustrates how the speedometer needle has been illuminated by a 5mm LED lamp. It also illustrates what improvement could be achieved by using a more efficient light guide.

The addition of light control film improved both the contrast, and legibility under extreme ambient lighting conditions, but it severely limited the viewing angle of the free format display to an unacceptable level in terms of viewing from any position other than that of the driver's seat. It would be more appropriate to use a combination of anti-reflection coatings, which are now commonly

Fig. (28) In Car GPS
 BMW introduced this TFT LCD in
 their latest '7' series saloon as
 an option. It can provide GPS
 navigation and even TV pictures.

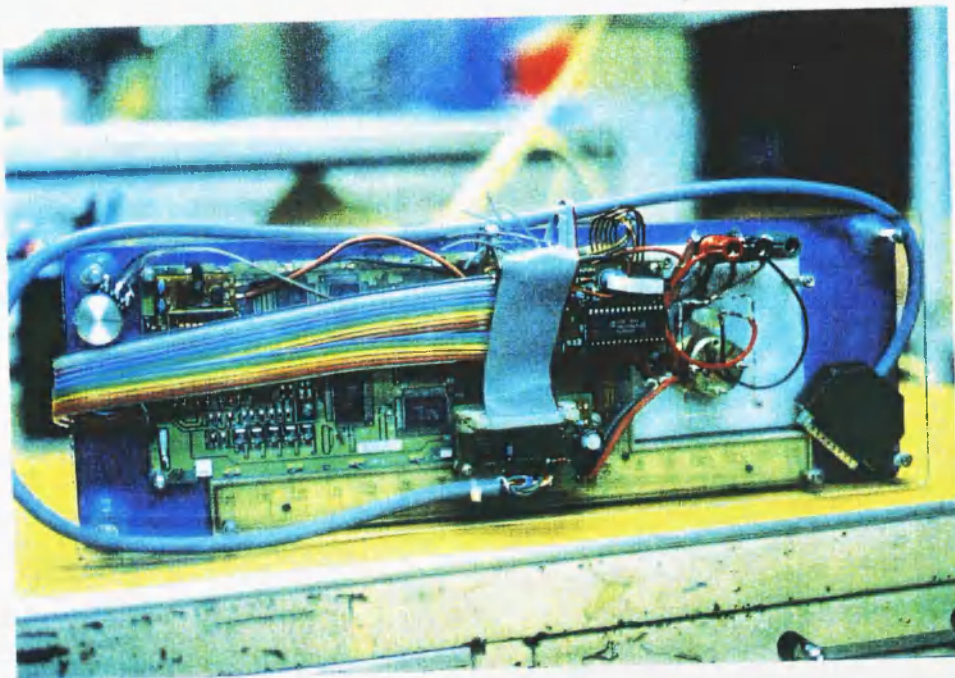
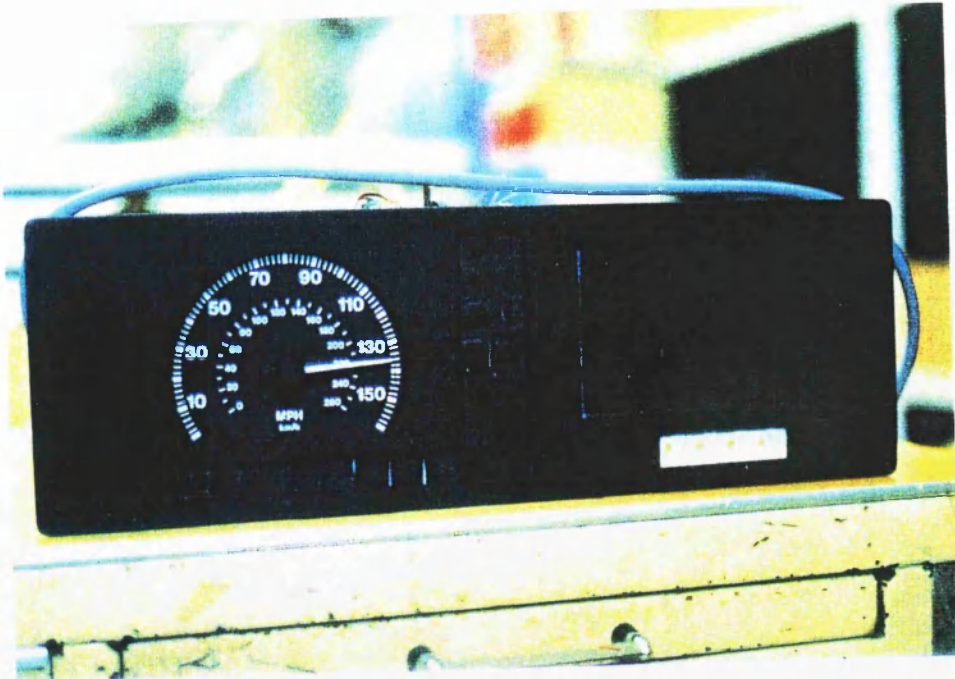


available on the market, especially in the case of the free format display. The LED indicators would certainly benefit from the addition of the light control film as it is of little consequence, generally, if these are not visible from the other areas of the cabin, particularly as the free format display would be offering supplementary diagnostics that were. Fig. (29) shows the completed model, and highlights the very compact nature of the arrangement.

Undoubtedly, the level of information that it will be necessary to produce in future automobiles will require a radical development of instrumentation. The model developed in the course of this study illustrates how these demands can be satisfied, without departing radically from traditional styles. It also proves the advantage of integrating a common system into the body electronics. Recent developments have indicated that advanced full-colour AMLCDs are becoming more accessible in terms of price, and general availability. This should mean that a great deal more of the desired characteristics are available at a price that makes integration of such displays practical beyond the luxury marques. Certainly, the facility for reproducing cartographic detail would be possible, as would the ability to issue warning diagnostics in the appropriate colour. It would also mean that the entertainment facilities could be considerably extended. The move by BMW, whilst predominantly of novelty value at present, proves the natural progression towards such schemes. They solve many of the needs at hand without challenging tradition to an unacceptable level. The longer term future for automotive instrumentation is less clear. Fig. (18) has illustrated one manufacturer's vision of the future. The integration of equipment that improves visibility, replaces mirrors, and provides proximity information has already been prototyped by many manufacturers. Honda indeed has provided proximity sensing as standard in its 'Odyssey' recreation vehicle. The cost of all this technology will fall. It will become increasingly practical to implement such services in a wider range of vehicles. Producing such vehicles at a lower cost will require the implementation of common components and systems. Safety will be targeted by reducing the level of user interaction. Head-up displays (HUD) will become increasingly prevalent. HUD systems provide the user with information that is instantly recognisable, without the need to divert attention from the forward direction. It uses such techniques as Snellen figures to project an image that appears to be in focus some way ahead of the vehicle^{xxiv}, dispensing with the need to re-focus the eyesight to read an instrument that has been placed close at hand. The further development of the optics required by such schemes, and the standardisation of accurate ways of implementation will result in their introduction in the very near future. However, because the majority of the demands on the driver of a vehicle are based on what is perceived visibly there will be a general trend towards supplementing information audibly, as opposed to visually.

Fig. (29) Final Assembly

Front and rear view of the completed assembly. Simplified layout of final assembly contrasts starkly with the more cluttered arrangement of the original model (cf Fig. 20). The rear view is obscured by the parallel port cable and power supply connections. A conventional wiring loom, or data bus would simplify this arrangement.



This study has clearly defined the direction in which automotive instrumentation has to move. It is clear that instrumentation needs to adapt along two lines. First of all primary information has to be provided in a manner which is immediately comprehended by the driver, without compromising their ability to safely operate the vehicle. Secondly, the instrumentation must meet the demands for more diagnostics, news and entertainment. All of this must be done whilst adhering to the wishes of the stylist. This document has studied, in depth, the way future display technology may progress, and how it may be integrated into the automobile. The greatest challenge is to catalyse this movement in a way that is acceptable to today's world-wide driving population. An effective first step has been offered by the work described here.

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- ⁱ *Electronic Displays* - Sol Sherr (John Wiley & Sons - ISBN 0-471-02941-6; 1979)
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Appendix

Display Characterisation

Parameter	Direct-view FPD	Projection FPD
Size	3" - 10"	5" - 4.0"
Resolution	80 Color Dots per Inch Minimum 320 X 240 - 640 X 480	120 Color Dots per Inch Minimum 60 Color Dots per Degree Desired
Color	3 Bits, 512 Colors 4 Bits, 4096 Colors	Same
Power	5 - 10 Watts (Not Primary Consideration)	30 Watts Maximum
Storage Temperature	-40 to +85 Degrees Centigrade (-40 to +105 Some Applications)	Same
Powered Temp Cycle	-40 to +85 Degrees Centigrade 500 Cycles	Same
Performance Temperature	-20 to +70 Degrees Centigrade (Broader for Some Applications)	Same
Humidity	+65 Degrees Centigrade 95% Relative Hum, 168 Hrs	Same
Vibration	3.2 g Random/Multiaxis	Same
Viewing Angle	60 Deg Vert, 100 Deg Hor (Broader for Some Applications)	40 Degrees Vertical 120 Degrees Horizontal
Contrast Ratio	50:1 Minimum, Dark Background 10:1 Min at 3000 lx Surf Illum	100:1 Min, Dark Background
Response Time	Video 50 ms at 25 Deg Cent Graphic 100 ms at 25 Deg Cent	Same
Operating Voltage	8.0 - 18.0 VDC	Same
Brightness	350 cd/sq m 100:1 Dimming Ratio Minimum	40,000 cd/sq m 100:1 Dimming Ratio Minimum
Defective Pixels	1 per Display Failed Bright 1 per Square Inch Failed Dark	Same
EMC	Minimum (Per GM 9100P)	Same
Weight	Laptop PC Standard	(Not an Issue)

Fig. 1. Automotive FPD Specification Requirements

harsh with respect to temperature extremes, humidity, and ultraviolet exposure. As demonstrated by the specifications for storage temperature, powered temperature cycling, performance temperature, humidity, and UV exposure, the automotive environment definitely challenges electronic components in general and flat-panel displays in particular.

Potential Solutions

The most likely flat-panel display candidate technologies can be stated simply. Today VFD and TNLCD are the display technologies of choice. In the midterm, AMLCD's will find utility in automotive reconfigurable displays, and in the long term it is not clear whether the AMLCD or the FED will dominate high-content automotive usage. In considering the candidate technologies for flat-panel displays in cars, we divide the world into two halves, which represent the two major types of display applications. First of all, there are direct-view flat panels in the range of 3" to 10" on the diagonal, and then there are projection image sources for head-up displays on the order of 1/2" to 4" on the diagonal.

We have developed an analysis tool which allows us to summarize very quickly the strengths and weaknesses of candidate technologies relative to these two

types of displays. The technique plots a spider chart, which is an eight-axis graph representing eight of the most important parameters or attributes with respect to automotive applications. The axes of the spider charts have been set up so that ideal or nearly ideal values are found at the outer extremes of the axes. The nearly ideal display technology would plot an octagon, or web, if you will, of maximum diagonal length.

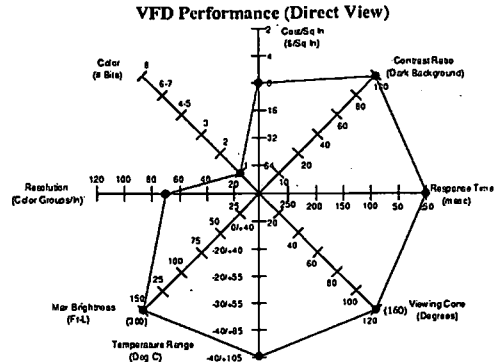


Fig. 2. Direct-view Dot-matrix VFD Performance

Consideration of vacuum-fluorescent display performance shows very quickly why VFD finds its strength in the automotive arena. It is strong with respect to cost, contrast ratio, response time, viewing cone, operating temperature range, and maximum brightness. VFD exhibits weaknesses only in that it is limited to low- and medium-information-content resolutions, and it has limited capabilities for color.

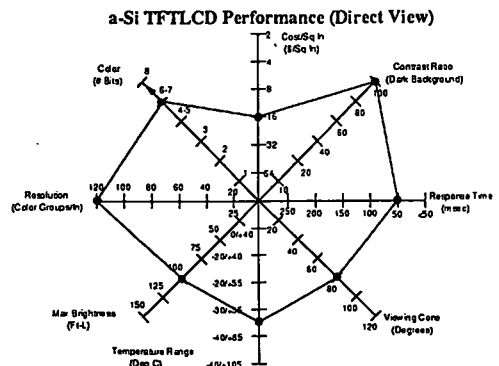


Fig. 3. Direct-view AMLCD Performance

On the other hand, amorphous silicon AMLCD technology provides answers for the weaknesses of VFD with respect to color and resolution, but AMLCD technology is severely lacking with respect to cost, and

3.2 / Schumacher

it leaves some to be desired with respect to viewing conc, operating temperature range, and maximum brightness.

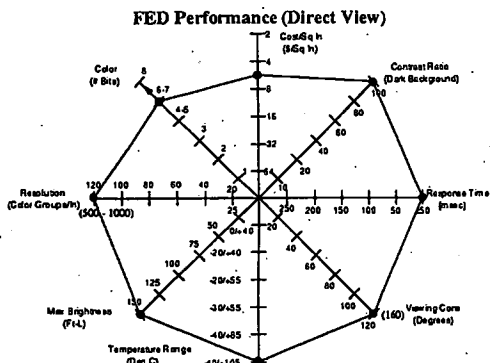


Fig. 4. Anticipated Direct-view FED Performance

In the long term, FED may answer the weaknesses left by AMLCD, but it should be remembered that, at this point, FED receives the benefit of the doubt with respect to performance, because very little direct experience is available, and the FED is early in its development cycle.

VFD is a strong contender in HUD products for the very same reasons that it works well in direct-view types of displays. Its only limitations exist with respect to resolution and color production.

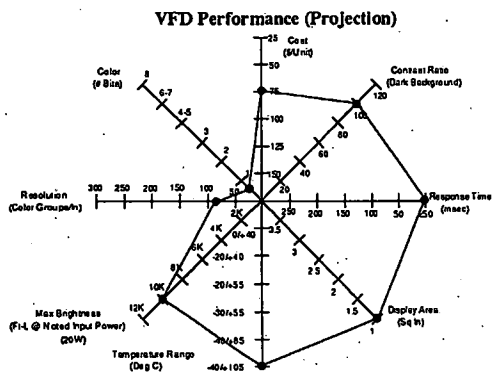


Fig. 5. Projection (HUD) Dot-matrix VFD Performance

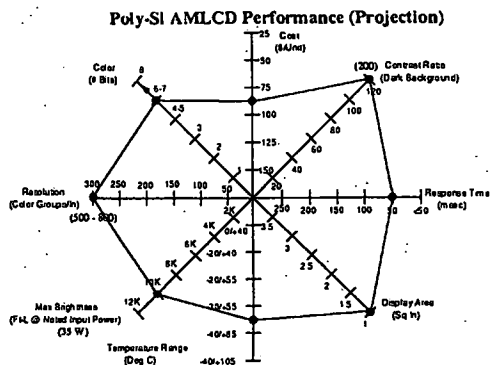


Fig. 6. Projection (HUD) AMLCD Performance

Similar to amorphous silicon AMLCD's in direct-view applications, polysilicon AMLCD's answer the issues left by VFD with respect to color and resolution in HUD products, but they carry with them problems with respect to cost, operating temperature range, and maximum brightness for HUD applications.

Again, in the long term, field emission displays potentially could answer most or all of the needs of automotive head-up display applications.

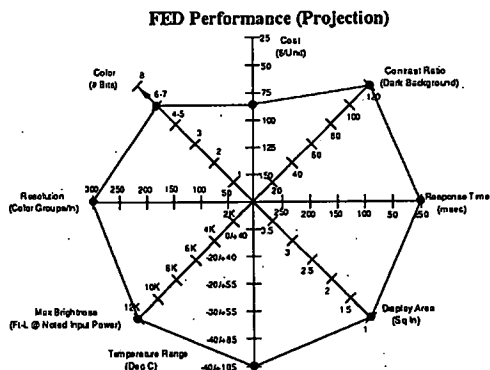


Fig. 7. Anticipated Projection (HUD) FED Performance

Anticipated Future Direction

The exact dimensions and specifications for flat-panel displays will vary by specific application, and many of these applications are yet to be fully defined.

This is as much as to say that the exact size and shape of displays required for automotive applications is a matter of conjecture at this point. However, we see the need for a color reconfigurable image source in the range of 1" to 1-1/2" for general-purpose head-up displays. This HUD need will be augmented potentially

Basic Automotive FPD Needs

Display Type	Diagonal	Aspect Ratio	Color	RGB Groups
Generic HUD	1" - 1.5"	2:1 - 3:1	Color	77K
Night Vision HUD	3" - 4"	2.5:1	Mono	77K
Secondary Direct View	5" - 6"	4:3	Color	77K
Generic Instrument Cluster	6" - 12"	2.5:1 - 4:1	Color	77K - 307K

Fig. 8. Types of Automotive FPD Needs

by a 3" to 4" diagonal monochrome display for Night Vision applications. Secondary direct-view displays, as might be used for entertainment or navigation, will be on the order of 5" to 6" on the diagonal and will be color. A general-purpose instrument cluster potentially could be provided by a 6" to 12" color display. The resolution of these displays would be in the range of 1/4 VGA to VGA. Also, it should be noted that typically the most desirable aspect ratio for automotive displays is not 4:3, but somewhere around 2:1 or 3:1.

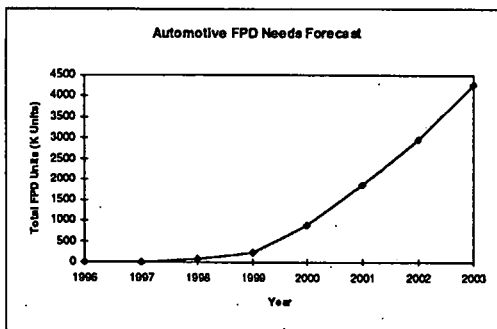


Fig. 9. Automotive OEM FPD Unit Volume Forecast

As we forecast the automotive OEM need (aftermarket not included) for flat panels worldwide based on our own experience, we see the serious portion of the volume ramp beginning approximately calendar year 2000. The growth in units could be fairly dramatic for the first three to five years to approximately 5 million units a year. At the same time, the average cost

of the displays being used will necessarily be decreasing in order to realize the increased volume. The decrease in unit cost superimposed on the volume ramp in units could give a total value of the automotive display market on the order of \$500 million by the year 2003.

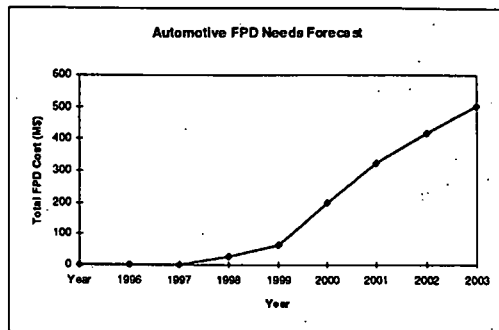


Fig. 10. Automotive OEM FPD Dollar Volume Forecast

Summary

Automotive applications for flat-panel displays are quite exciting. Performance requirements for these applications are quite stringent. Additionally, automotive applications are extremely cost sensitive. These facts lead to the conclusion that, while flat panels easily can be predicted to be a pervasive feature in future automobiles, work remains to effectively apply them. The future automotive market for FPD's will easily warrant addressing these remaining issues in order to develop the market. The future of flat panels in automobiles appears to be assured and promising.

Acknowledgments

The author would like to thank Dave Beyerlein, Tim Kennedy, and Karl Stone for contributions provided for this paper.

LCD Controller Specifications

MSM6255

DOT MATRIX LCD CONTROLLER

GENERAL DESCRIPTION

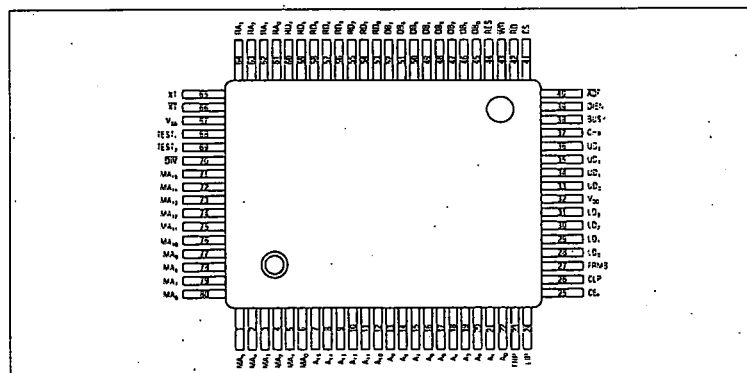
The MSM6255CS is a CMOS si-gate LSI designed to display characters and graphics on a DOT MATRIX LCD panels in characters and graphics.

FEATURES

- Display control capacity
 - Graphic mode: 512,000 dots (2¹⁶ bytes)
Memory address MA₀ ~ MA₁₅
 - Character mode: 65,536 characters (2¹⁶ bytes)
Display address MA₀ ~ MA₁₅
- Direct interface with 8085 or Z80 CPU
- Duty: 1/2 to 1/256 selectable
- Attributes
 - Screen clear
 - Cursor ON/OFF/blink
- Scrolling and paging
- Display system: AC inversion at each frame
- Data output (upper and lower display outputs)
 - 4-bit parallel output, 2-bit parallel output, 1-bit serial output
- Crystal oscillation
- Low C-MOS Silicon gate process
- Single +5V power supply
- 80 pin plastic QFP (QFP80-P-1420-K)
- 80 pin -V1 plastic QFP (QFP80-P-1420-V1K)

PIN CONFIGURATION

(Top view) 80 pin plastic QFP



General Description

The SED1330 is a graphics and character display controller for use with medium scale dot matrix LCDs. This CMOS LSI device generates all the signals required by the display memory and LCD drivers, and incorporates a character generator ROM, so that flexible, low power, display systems can be designed with a minimum number of external components.

The SED1330's high speed MPU interface can be configured for both 6800 family and 8080 family processors, and the rich command set allows the user to create a layered display of characters and graphics, scroll the display, and assign display attributes to selected areas of the screen, with a minimum of MPU intervention. The controller also functions as a pipeline buffer between the MPU and display memory so that low cost, medium speed SRAM can be used.

The device's character generator system supports user-defined characters, which can be used alone, or in conjunction with the on board character set.

Recommended LCD drivers

- X: SED1180F, SED1600F
- Y: SED1190F, SED1610F, SED1630F

Related devices

- EG-2401S-AR LCD panel
- EG-2801S-AR LCD panel
- EG-4401S-AR LCD panel
- EG-4801S-AR LCD panel

Features

- 6800 and 8080 family compatibility, 2 pin programmable
- Programmable cursor movement
- Flexible scrolling
 - Scrolling in both horizontal and vertical directions
 - Scrolling of selected areas of the display
- Multimode display

- Up to 2 layers of mixed character and graphics
- Up to 3 layers of graphics
- Selectable display synthesis
 - Display Attributes (Reverse Video, Flashing, ect) for selected areas of the display
 - Simple animation
- Supports 64Kbytes of memory
- 160 JIS 5x7 pixel characters internal
- Supports external character ROM and RAM
 - Up to 256 characters
 - 8x8 or 8x16 pixel characters
 - Allows mixing of ROM and RAM character sets
- Variable LCD duty cycle, from $\frac{1}{2}$ to $\frac{1}{256}$
- Low power CMOS fabrication
 - 5mA (typical)
 - 0.05 μ A (typical), standby
- Single 5V supply
- Choice of packages
 - SED1330FBA (60 pin FP-5)
 - SED1330FBB (60 pin FP-6)

ESD

MERCATOR

SOUTH DENVES
GT. YARMOUTH
NORFOLK NR30 3PX
TEL (0493) 844911
TELEX 975441
FAX (0493) 852443

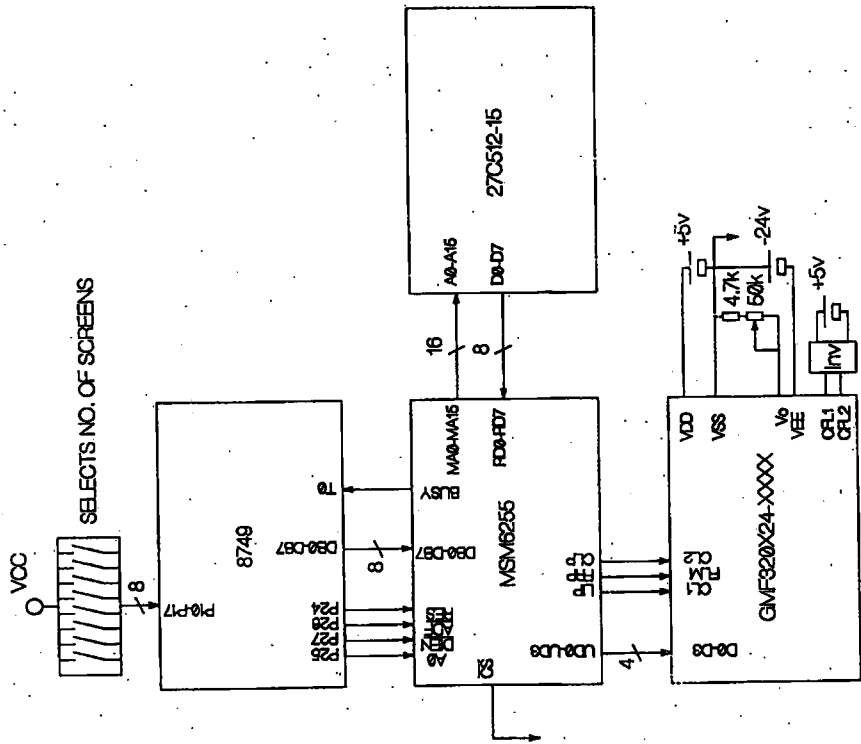
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DRAWING NO.
MSM42553A/FBD

DESCRIPTION
Block Diagram for LCD
Controller Board

CUSTOMER
ESD Mercator

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3M Light Control Film Specification



Industrial Optics Light Control Film

3M

Product Description

3M Light Control Film (LCF) is a thin plastic film containing closely spaced black microlouvers. The film simulates a tiny venetian blind to shield out unwanted ambient light and direct display light of electronic instrumentation. LCF, with variable louver orientation, enhances contrast of electronic displays or blocks nighttime windshield reflections from instrumentation.

Three product variables—viewing angle, louver angle and louver type—determine the optical performance that can be attained with LCF. Figs. 1a, b (Light Control Film)

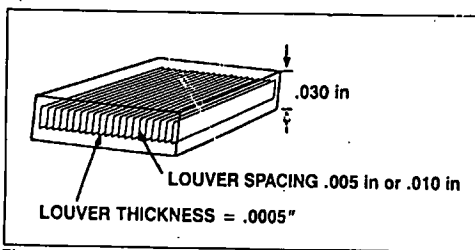


Fig. 1a

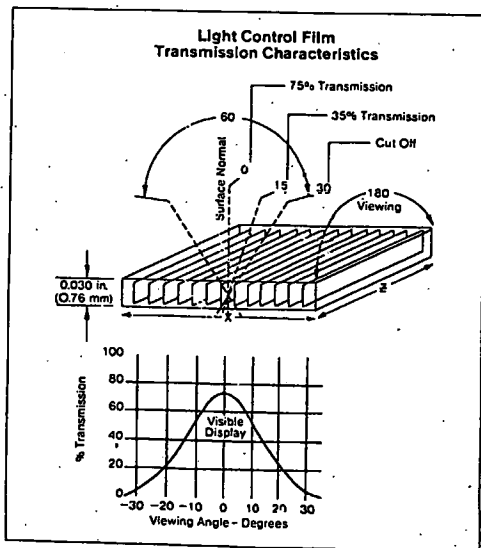


Fig. 1b

Product Applications

Light Control Film can be used with a variety of electro-optical displays such as light emitting diodes (LED), vacuum fluorescent displays (VFD), electroluminescent panels (EL), liquid crystal displays (LCD), incandescent lights and cathode ray tubes (CRT).

— **Privacy Viewing** - Light Control Film allows for controlled viewing, so that unauthorized observers will have their line of sight blocked. It is ideal for confidential viewing on CRT's, Automatic Teller Machines (ATM) and anywhere privacy viewing may be desired. Fig. 2

— **Sunlight Readability** - Light Control Film micro-louvers help block out annoying off-axis light while maximizing the transmission from the display to the viewer. The result is improved display contrast with little loss of brightness. Fig. 3

— **Light Directing** - Light Control Film directs light to where it is needed or away from where it is not. It eliminates nighttime window reflections in automotive and aeronautical applications. It can also be used to hide the light source in incandescent lighting applications. Fig. 4

— **Contrast Enhancement** - Light Control Film improves contrast and reduces glare on electronic displays by blocking out annoying off-axis light, making the display more comfortable to read. The micro-louvers maximize the transmission from the display to improve the image with little loss of brightness.

Fig. 2 Privacy Viewing

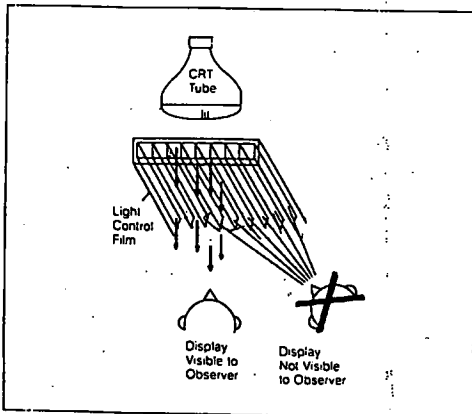


Fig. 2

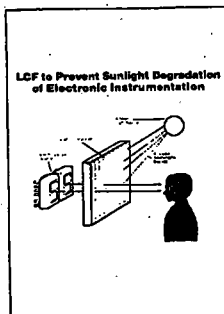


Fig. 3

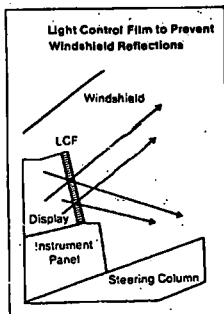


Fig. 4

Light Control Film Options

Light Control Film is available with a number of options to match display readability or lighting requirements. The options are as follows:

- Louver Angle
- Viewing Angle
- Louver Type
- Color
- Abrasion/Solvent Resistance
- Surface Finish
- Thickness

Each of these options is explained in more detail with option codes in the next sections.

Louver Angle

The louver angle is the angle at which the maximum amount of light is transmitted through the Light Control Film. This angle corresponds to the peak value of the response curve (see Fig. 5). The louver angle most commonly used is 0° , but in those applications where the display light is to be diverted away from a normal to the film surface, LCF is available with three different louver orientations (see Fig. 6). Typical maximum transmission value is 75%; actual transmission values vary with louver type and surface finish.

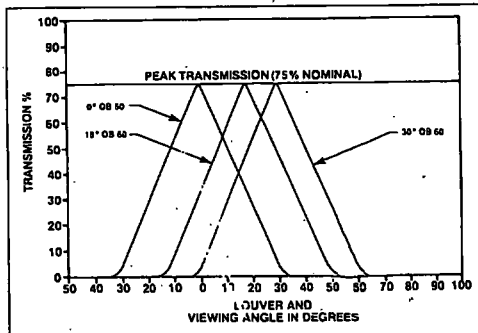


Fig. 5

Light Control Film - Louver Orientation

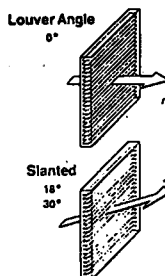


Fig. 6

Option Code:

LCF 0° — Maximum transmission is normal to the film surface.

LCF 18° — Maximum transmission is 18° from normal to the film surface.

LCF 30° — Maximum transmission is 30° from normal to the film surface.

Viewing Angle

The viewing angle is the area allowing light to pass between the louvers. Fig. 7. The shape of the response curve is defined by a bell shaped curve which is symmetrical about the louver angle or location of the maximum transmission value. Light transmission decreases symmetrically about the louver angle until cut off is reached. Cut off is defined as the angle which is 5% of maximum transmission.

Light Control Film - Louver Orientation

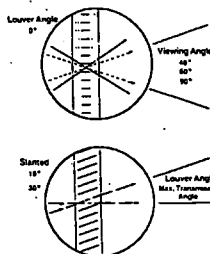


Fig. 7

Option Code:

48° — total included viewing angle is 48° about the louver angle

60° — total included viewing angle is 60° about the louver angle

90° — total included viewing angle is 90° about the louver angle

Louver Type

Three types of louvers are available with Light Control Film; the standard type being opaque black.

Option Code:

OB—Opaque Black. These louvers have total cut off and are best used for the attenuation of incident ambient light (sun light) and directional control of bright artificial light sources. Nominal maximum transmission is 75%.

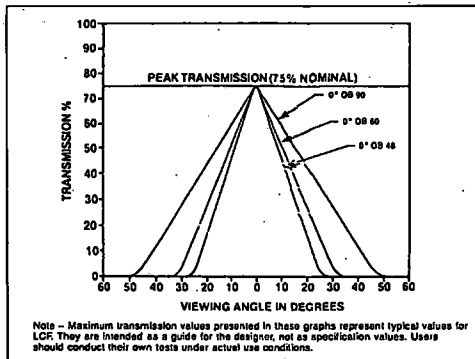


Fig. 8

TB—Transparent Black. These louvers have about 10% transmission at cut off and are generally preferred where sudden total cut off is not wanted. It is also recommended for displays which rely on ambient light for daytime viewing but require incandescent, auxiliary illumination for nighttime viewing. The transparent black louvers allow some off-axis light to pass through to the display, and depending on the light source intensity, are sufficient for preventing or minimizing nighttime windshield reflections. Nominal maximum transmission is 78%.

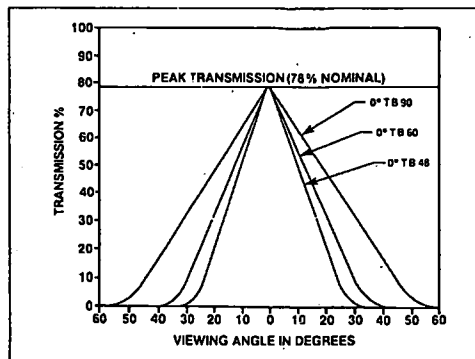


Fig. 9

AG—Antighosting opaque black. These opaque black louvers have similar cut off properties as OB

type louvers. They are generally preferred for use with high intensity electro-optical displays to reduce the effects of multiple imaging (ghosting). Nominal maximum transmission is 70%.

Color

Light Control Film is available either clear or in colors. 3M custom matches its color filters to the spectral emission characteristics of electronic displays—Vacuum fluorescent, light emitting diodes, cathode ray tubes and electroluminescent panels—for example.

The color data and spectrophotometric transmission curves describe some of the characteristics and recommended applications. The color data shown is for the color component of LCF only, surface finish and louver construction will decrease the transmittance values.

Option Code:

ND0205 — Neutral Density 70% photopic transmittance

ND0210 — Neutral Density 50% photopic transmittance

ND0215 — Neutral Density 38% photopic transmittance

ND0220 — Neutral Density 27% photopic transmittance

B0706 — Blue-green 33% photopic transmittance

B0712 — Blue-green 12% photopic transmittance

G5210 — Green 23% photopic transmittance

R6310 — Red 10% photopic transmittance

Photopic Transmittance is the integrated visible transmittance of the color filter, corrected for the human visual response.

Applications

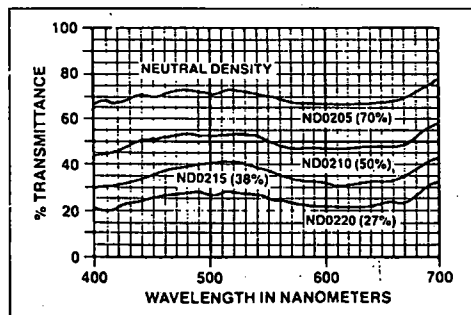
Neutral Density

ND0205 — All CRT phosphors

ND0210 and any multi-color display

ND0215

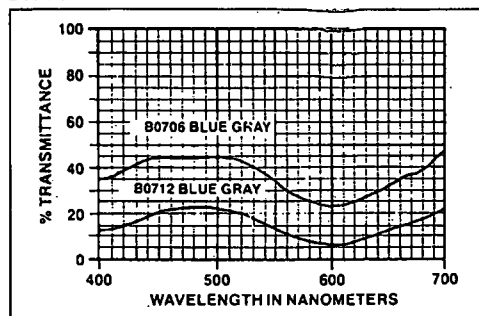
ND0220



Blue-green

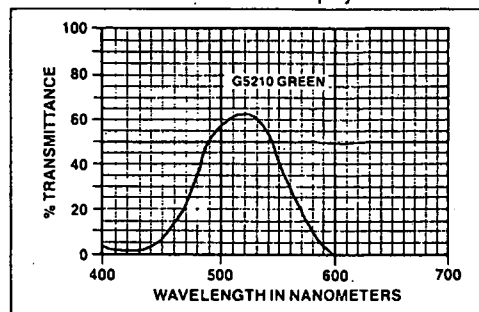
B0706 — Vacuum fluorescent displays

B0712



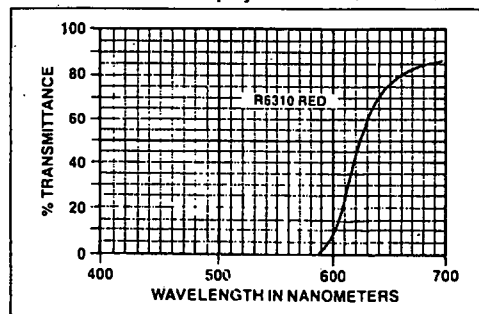
Green

G5210 — P1, P31, P39, P42 CRT phosphors and vacuum fluorescent displays



Red

R6310 — P12, P25, P27, P33 CRT phosphors and red LED displays 625 to 655 nanometers



Abrasion/Solvent Resistance

The Abrasion/Solvent Resistant option imparts both abrasion and solvent resistance to the treated surface of the Light Control Film. This option is permanently adhered to the film and will not chip,

peel, or flake from the substrate. It is clear and transparent, adding less than 0.5% haze to the base material. This option is not available with slanted LCF (0° louver angle only).

— Taber Abrasion Test: Nominal 15% haze increase above the substrate value per ASTM D1044-73.

— Falling Sand Test: Nominal 20% haze increase above the substrate value per ASTM D968-51.

Solvent Resistance: No detectable change in abrasion and solvent resistance of Light Control Film after 24 hour continuous exposure of:

Methanol*	Lipstick
Ethanol*	Coca Cola
Acetone*	Coffee
Chloroform*	Liquid Soap
5% Acetic Acid	Rubber Cement
Toluene*	MEK*
Gasoline	Windex
Oil	Isopropyl Alcohol*

Light Control Film without the Abrasion and Solvent Resistant surface will be affected by the above materials.*

Option Code:

ABR0 — Neither surface of the film is abrasion/solvent resistant

ABR2 — Both surfaces are abrasion/solvent resistant.

Surface Finish

The surfaces of Light Control Film are available as glossy (both sides) or with various degrees of matte (one surface matte, one surface glossy). The choice between these surface finishes is often very subjective, being a compromise between specular and diffuse reflectance, and display character resolution. Matte finishes can reduce but not eliminate first surface glare (specular reflections).

Option Code:

GLOS — Glossy both surfaces

VLM — Very Light Matte (not available with ABR2)
Gardner Glossmeter readings typically:
90 units @ 85°
125 units @ 60°

ABM6 — Abrasion Resistant Matte (available only with ABR2) Gardner Glossmeter readings typically:
85 units @ 85°
60 units @ 60°

LM — Light Matte (not available with ABR2)
Gardner Glossmeter readings typically:
55 units @ 85°
27 units @ 60°

Material Thickness

Light Control Film is available in thicknesses from .030" to .050"

Option Code:

.030" ± .005
.050" ± .005

Physical Properties

Substrate: Cellulose Acetate Butyrate (CAB)

- Refractive Index: $1.48 \pm .01$
- Abbe Number: 82 ± 2
- Specific Gravity: 1.20
- Rockwell Hardness: 99 R Scale
- Coefficient of Thermal Expansion: 14×10^{-5} in/in/C°
- Use Temperature Range: Maximum use temperature is dependent upon the application, part size and stress. CAB does not degrade when exposed to temperatures above 100°C (212°F), but does become progressively softer. Specific ASTM and material supplier data:
 - Deflection Temperature (ASTM D648-72) 264 psi fiber stress at 67°C (152°F) 66 psi fiber stress at 80°C (176°F)

Small or supported filters may withstand sporadic exposure to higher temperatures. Maximum continuous operating temperature which should not result in material degradation is 71°C (160°F). CAB retains excellent physical properties at temperatures below -40°C (-40°F).

- Flammability (LCF): 3M Light Control Film is a recognized plastic component meeting UL flammability classification 94 HB with or without

3M Abrasion/Solvent Resistant surfaces at .047" (1.19mm) minimum thickness.

3M Light Control Film meets burn rate Vehicle Safety Standard No. 302 requirements with and without Abrasion/Solvent Resistance surfaces when flame propagation is perpendicular to the lower direction and at a minimum of .030" overall thickness.

Converted Parts

LCF can be screen printed with a variety of ink screening configurations and color matching, if required. The parts may be die cut to meet specific applications. Adhesive application is also available. 3M welcomes requests for specialty converted LCF parts.

Mounting Procedures

LCF can be mechanically mounted with a frame or bezel, or supported by a cover sheet. Die cut parts can be converted with holes for heat staking.

Many 3M mounting adhesives are available on finished parts, whether selective or complete adhesive coverage is required. These adhesives mount filters directly to the display. Transfer tapes (strips) or double coated tapes (gaskets) adhere the film only to the display edges.

ISO Symbol Specifications

Annex II Note (d)

Since the text suggests that one symbol may suffice for a multi-function control it would be acceptable for a headlamp dip switch to carry only figure 2 or figure 3, but if the same also operates the side lights it would be necessary to have at least one of the headlight symbols and the side light symbol. However, if the switch controls all the lights defined in paragraph 2.10 it is only necessary to use the symbol in figure 1.

Annex II Figures 12, 13 and 14

Since the titles of figures 12 and 13 do not contain the words "if separate" it is acceptable to use symbols 12 and 13 on a combined wash/wipe control.

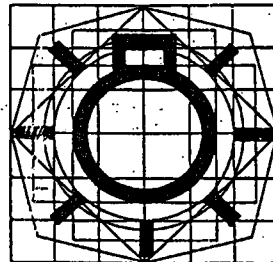
Annex II Figure 19

Since there is no definition in the Directive of "cold starting device" it must be assumed that this symbol is applicable to all types including "glow plugs".

Figure 1

Master lighting switch and driver-chosen on/off (7) or combined on/off-master switch for lighting

Standard symbol



Colour of on/off lights green



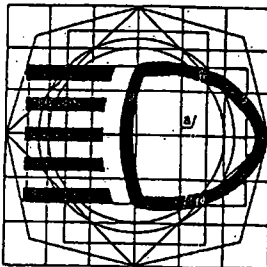
(7) The symbol may not be used as the symbol for the power window switch.

FIG. JVS: 101EE:01:01

Figure 2

Main-beam headlamp control, if separate (R), and circling-around off-side

Standard symbol



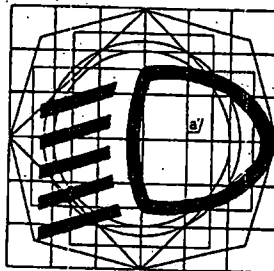
Colour of off-side light: blue

FIG. JVS:101EE:02:01

Figure 3

Dipped-beam headlamp control, if separate (R), and circling-around off-side

Standard symbol



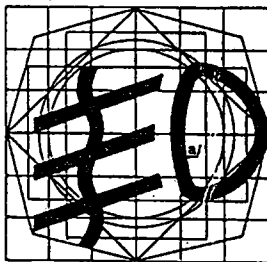
Colour of off-side light: green

FIG. JVS:101EE:03:01

Figure 4

Front lamp control and circling-around off-side

Standard symbol



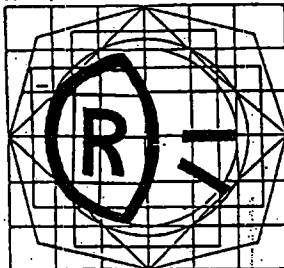
Colour of off-side light: green

FIG. JVS:101EE:04:01

Figure 5

Separate reversing lamp control (where fitted) and circling-around off-side

Standard symbol of



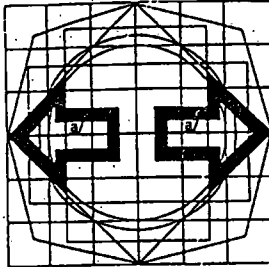
Colour of off-side light: green

FIG. JVS:101EE:05:01

Figure 6

Direction-indicator lamp control and expression of sub-scale (B)

Standard symbol



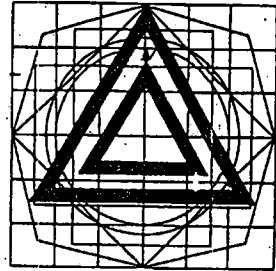
Colour of sub-scale light: green

FIG. JVS:101EE:06:01

Figure 7

Forward-warning signal and circular-chose sub-scale

Standard symbol



Colour of sub-scale light: red

FIG. JVS:101EE:07:01

Stop lamp sub-scale

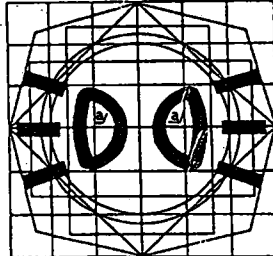
If limit, an function must be performed by the breaking system defective expression sub-scale, which is shown in Figure 2A.

FIG. JVS:101EE:08:01

Figure 9

Position (side) lamps control, if separate (A), and position (side) lamps circular-chose sub-scale

Standard symbol



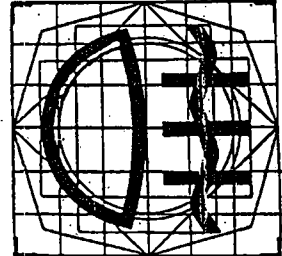
Colour of sub-scale light: green

FIG. JVS:101EE:09:01

Figure 10

Rear lamp(s) control and circular-chose sub-scale

Standard symbol



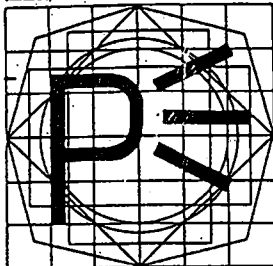
Colour of sub-scale light: amber

FIG. JVS:101EE:10:01

Figure 11

Furling lamp(s) covered, V square(s) (4), and circuit-closed all-side

Standard symbol



Colour of all-side light: green

FIG. JVS:101EE:11:01

Figure 12

Windscreen-wiper covered

Standard symbol

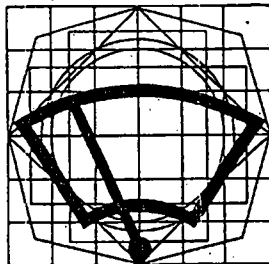


FIG. JVS:101EE:12:01

Figure 13

Windscreen-wiper covered

Standard symbol

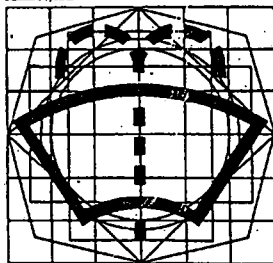


FIG. JVS:101EE:13:01

Figure 14

Combined windscreen-wiper and windscreen-washer covered

Standard symbol

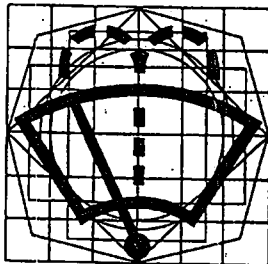


FIG. JVS:101EE:14:01

Figure 10

Fan (warn not cold air) symbol

Standard symbol

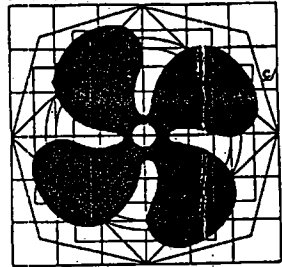
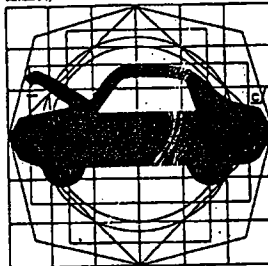


FIG. JVS:101EE:16:01

Figure 13

Front bumper repair symbol (*)

Standard symbol



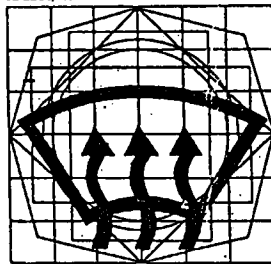
*) If the symbol manufacturer or symbol system 111 of Annex I shall not apply, when this symbol is not visible the driver's field of vision shall be normal during operation.

FIG JVS:101EE:15:01

Figure 17

Windscreen defroster and demister control, if separate, and left-side

Standard symbol



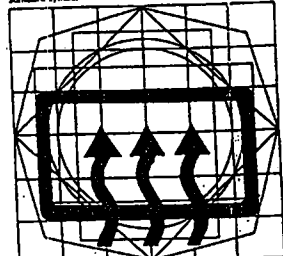
Colour of left-side light: amber

FIG:JVS:101EZ:17:01

Figure 18

Rear window defroster and demister control, if separate, and left-side

Standard symbol



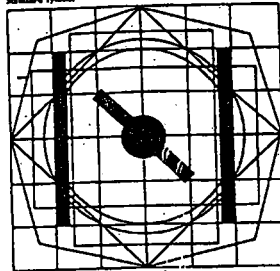
Colour of left-side light: amber

FIG. JVS:101EE:18:01

Figure 19

Cold-starting device symbol

Standard symbol



Colour of self-able light: amber

FIG. JVS:101EE:19:01

Figure 20

Figure 20

Hand-starting device symbol

Standard symbol

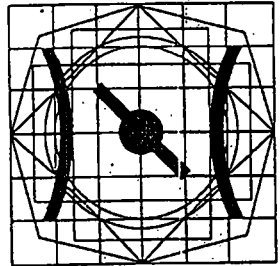
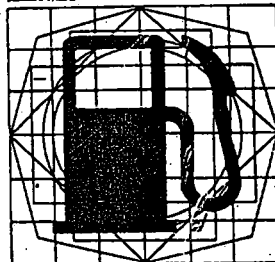


FIG. JVS:101EE:20:01

Fuel-level indicator and self-able

Standard symbol



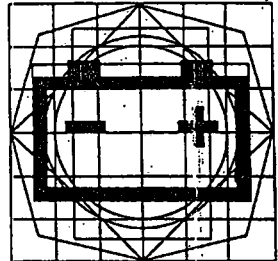
Colour of self-able light: amber

FIG. JVS:101EE:21:01

Figure 22

Battery-charging indicator and self-able

Standard symbol



Colour of self-able light: red

FIG. JVS:101EE:22:01

Figure 23

(Over) engine speed control, if installed on dashboard

Standard symbol

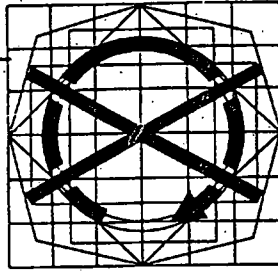
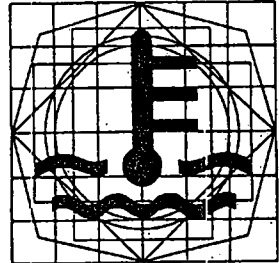


FIG. JVS:101EE:23:01

Figure 24

Engine coolant temperature indicator and sub-scale

Standard symbol



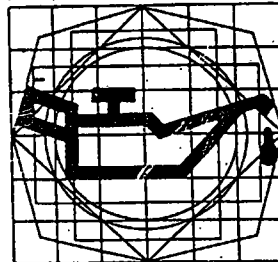
Colour of sub-scale light: red

FIG. JVS:101EE:24:01

Figure 25

Oil pressure indicator and sub-scale

Standard symbol



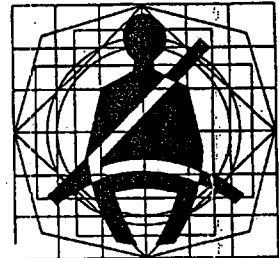
Colour of sub-scale light: red

FIG. JVS:101EE:25:01

Figure 26

Safety belt sub-scale

Standard symbol



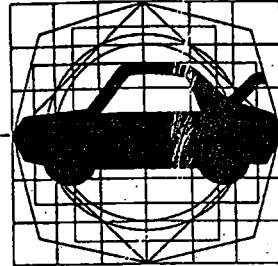
Colour of sub-scale light: red

FIG. JVS:101EE:26:01

Figure 1

Base-component driver educe manual

Standard symbol



Note
See note (G) in Annex II.

Fig JVS:101EE:29:01

Figure 2

Admissible warping device manual

Standard symbol

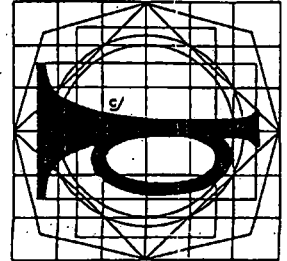


FIG. JVS:101EE:30:01

ANNEX IV

CONSTRUCTION OF THE BASIC PATTERN FOR THE SYMBOLS SHOWN IN ANNEXES I AND II

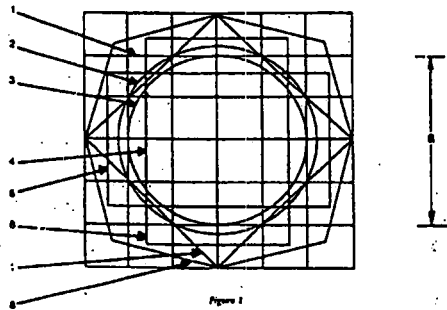


Figure 3

FIG JVS:101EE:31:01

Model Demonstration Software Listing

* HSSI.SYS REQUIRED

DEMOf = LPT1

DEMOf_2 = LPT2

```
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <string.h>
#include <dos.h>
#include <alloc.h>
```

```
FILE *fp;
unsigned char far *f=(unsigned char far *)0xb8000000;
int dir,allon=0,mode=0,scrbox=0,lampbox=0,x,y,z,lampstate[30];
char ch;
unsigned char screens[4][9600],huge *ptr;
char filenames[4][13]={"CAR.IMG","AIR.IMG","TRIP.IMG","RPM.IMG"};
long ptrptr,i;
unsigned int port;
```

```
main(int argc,char *argv[])
```

```
{
    if (argv[1][0]=='2')
        port=0x278;
    else
        port=0x378;
    ptr=farmalloc(120000);
    if (ptr==NULL)
        exit(0);
    fp=fopen("RPM.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM1.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM2.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM3.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM4.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM5.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM6.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM7.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM8.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM9.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM10.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
    fp=fopen("RPM11.IMG","rb");
    for(x=0;x<9600;x++) {*(ptr+ptrptr)=fgetc(fp);ptrptr++;} fclose(fp);
}
```

```

for(x=0;x<4;x++)
{
    fp=fopen(filenamees[x],"rb");
    for(y=0;y<9600;y++)
        screens[x][y]=fgetc(fp);
    fclose(fp);
}
initialise_screen();
lcd_setup();
load_leds();
while(1)
{
    if (mode==0)
        lmpcur(lampbox,1);
    else
        scrcur(scrbox,1);
    ch=toupper(getch());
    if ((ch=='F')&&(mode==0))
    {
        lampstate[lampbox]=2;
        if (lampbox<18)
            printf(lampbox*4+4+1,22,'0',15+128);
        else
            printf(((lampbox-18)%2)*4+36+1,20-(((lampbox-18)/2)*2),'0',15+
9);
    }
    if (ch==27)
        break;
    if ((ch==13)&&(mode==0))
    {
        if (lampstate[lampbox]==2)
            lampstate[lampbox]=0;
        else if (lampstate[lampbox]==0)
            lampstate[lampbox]=1;
        else lampstate[lampbox]=0;
        if (lampbox<18)
            printf(lampbox*4+4+1,22,'0',lampstate[lampbox]*15);
        else
            printf(((lampbox-18)%2)*4+36+1,20-(((lampbox-18)/2)*2),'0',lamp
state[lampbox]*15);
        load_leds();
    }
    if ((ch==13)&&(mode==1))
    {
        if (scrbox==4)
        {
            ptrptr=0;
            dir=1;
            while(1)
            {
                writ_comm(0x46);writ_data(0x00);writ_data(0x00);
                writ_comm(0x42);
                for(i=0;i<2400;i++)
                    writ_data(*(ptr+ptrptr+i));
                for(i=0;i<50000;i++);
                ptrptr+=9600*dir;
                if (ptrptr==115200)
                {
                    dir=-1;
                    ptrptr=96000;
                }
                if (ptrptr==--9600)
                {
                    dir=1;
                    ptrptr=9600;
                }
            }
        }
    }
}

```

```

        if (kbhit()!=0)
        {
            if (getch()==27)
                break;
        }
    }
}
else
    download(scrbox);
}
if ((ch==32)&&(mode==0))
{
    if (allon==0)
    {
        allon=1;
        for(x=0;x<30;x++)
        {
            lampstate[x]=1;
            if (x<18)
                printf(x*4+4+1,22,'0',lampstate[x]*15);
            else
                printf(((x-18)%2)*4+36+1,20-(((x-18)/2)*2),'0',lampsta
[x]*15);
        }
    }
    else
    {
        allon=0;
        for(x=0;x<30;x++)
        {
            lampstate[x]=0;
            if (x<18)
                printf(x*4+4+1,22,'0',lampstate[x]*15);
            else
                printf(((x-18)%2)*4+36+1,20-(((x-18)/2)*2),'0',lampsta
[x]*15);
        }
    }
    load_leds();
}
if (ch==9)
{
    if (mode==0)
    {
        lmpcur(lampbox,0);
        mode=1;
    }
    else
    {
        scrcur(scrbox,0);
        mode=0;
    }
}
if (ch==0)
{
    ch=getch();
    if (mode==0)
    {
        if ((ch==75)&&(lampbox!=0))
        {
            if ((lampbox<18)!!((lampbox%2)==1))
            {
                lmpcur(lampbox,0);
                lampbox--;
                continue;
            }
        }
    }
}

```

```

    }
    if ((ch==77)&&(lampbox!=17))
    {
        if ((lampbox<17)||((lampbox%2)==0))
        {
            lmpcur(lampbox,0);
            lampbox++;
            continue;
        }
    }
    if ((ch==80)&&(lampbox>17))
    {
        lmpcur(lampbox,0);
        if (lampbox>19)
            lampbox-=2;
        else
            lampbox-=10;
    }
    if ((ch==72)&&(lampbox<28))
    {
        if ((lampbox<8)||((lampbox>9)&&(lampbox<18)))
            continue;
        lmpcur(lampbox,0);
        if (lampbox<10)
            lampbox+=10;
        else
            lampbox+=2;
    }
}
else
{
    if ((ch==75)&&(scrbox!=0))
    {
        screur(scrbox,0);
        scrbox--;
        continue;
    }
    if ((ch==77)&&(scrbox!=4))
    {
        screur(scrbox,0);
        scrbox++;
        continue;
    }
}
}
clear_screen();
}

lmpcur(int box_no,int state)
{
    int color;
    if (state==0)
        color=0;
    else
        color=15;
    if (box_no<18)
    {
        printf(box_no*4+4,22,"[",color);
        printf(box_no*4+6,22,"]",color);
    }
    else
    {
        printf(((box_no-18)%2)*4+36,20-(((box_no-18)/2)*2),"[",color);

```

```

}
screur(int box_no,int state)
{
int color;
if (state==0)
color=0;
else
color=15;
box_draw(4+15*box_no,3,10,3,color);
}

initialise_screen()
{
clear_screen();
for(x=0;x<30;x++)
lampstate[x]=0;
box_draw(0,0,78,24,15);
print(2,0," Title ",15);
gotoxy(2,2);printc(1,1,0,0);
for(x=7;x<=71;x+=4)
{
printc(x,23,193,15);
printc(x,22,179,15);
printc(x,21,194,15);
}
for(x=4;x<=72;x+=4)
{
printc(x,21,196,15);
printc(x,23,196,15);
printc(x+1,21,196,15);
printc(x+1,23,196,15);
printc(x+2,21,196,15);
printc(x+2,23,196,15);
}
printc(3,21,218,15);printc(3,23,192,15);printc(3,22,179,15);
printc(75,21,191,15);printc(75,23,217,15);printc(75,22,179,15);
for(x=19;x>=11;x-=2)
{
printc(39,x,197,15);
printc(43,x,180,15);
printc(35,x,195,15);
printc(36,x,196,15);printc(37,x,196,15);printc(38,x,196,15);
printc(40,x,196,15);printc(41,x,196,15);printc(42,x,196,15);
}
for(x=20;x>=10;x-=2)
{
printc(35,x,179,15);printc(39,x,179,15);
printc(43,x,179,15);
}
printc(35,21,197,15);printc(39,21,197,15);
printc(43,21,197,15);
printc(35,9,218,15);printc(36,9,196,15);
printc(37,9,196,15);printc(38,9,196,15);
printc(39,9,194,15);printc(40,9,196,15);
printc(41,9,196,15);printc(42,9,196,15);
printc(43,9,191,15);
for(x=0;x<5;x++)
box_draw(3+x*15,2,12,5,15);
print(68,4,"PERF",15);
print(67,5,"ACTIVE",15);
print(53,4,"PERF",15);
print(52,5,"STATIC",15);
print(38,4,"TRIP",15);
print(38,5,"COMP",15);

```

```

print(23,4,"AIR",15);
print(23,5,"CON",15);
print(8,4,"CAR",15);
print(8,5,"MAP",15);

box_draw(int x,int y,int xx,int yy,int c)
{
    int w;
    printc(x,y,218,c);printc(x+xx,y,191,c);
    printc(x,y+yy,192,c);printc(x+xx,y+yy,217,c);
    for(w=0;w<xx-1;w++)
    {
        printc(x+w+1,y,196,c);
        printc(x+w+1,y+yy,196,c);
    }
    for(w=0;w<yy-1;w++)
    {
        printc(x,y+w+1,179,c);
        printc(x+xx,y+w+1,179,c);
    }
}

clear_screen()
{
    printf("%c[2J",27);
}

barb(int x,int y,int len,int col)
{
    int q;
    for(q=0;q<len;q++)
        *(f+1+((x+q)*2)+(y*160))=col;
}

print(int x,int y,char text[],int attr)
{
    int e;
    for(e=0;e<strlen(text);e++)
        printc(x+e,y,text[e],attr);
}

putc(int x,int y,unsigned char cha,int attr)
{
    *(f+(x*2)+(160*y))=cha;
    *(f+(x*2)+(160*y)+1)=attr;
}

attr(int x,int y)
{
    return(*(f+(y*160)+1+(x*2)));
}

lcd_setup()
{
    writ_comm(0x40);writ_data(0x34);writ_data(0x07);writ_data(0x07);
    writ_data(0x27);writ_data(0x2b);writ_data(0xef);writ_data(0x28);
    writ_data(0x00);
    writ_comm(0x4c);
    writ_comm(0x59);writ_data(0x04);
    writ_comm(0x5b);writ_data(0x04);
    writ_comm(0x5a);writ_data(0x00);
    writ_comm(0x44);writ_data(0x00);writ_data(0x00);
    writ_comm(0x46);writ_data(0x00);writ_data(0x00);
    writ_comm(0x42);
}

```

```

download(int x)
{
    int u;
    writ_comm(0x46); writ_data(0x00); writ_data(0x00);
    writ_comm(0x42);
    for(u=0; u<9600; u++)
        writ_data(screens[x][u]);
}

writ_data(unsigned char b)
{
    outportb(port, b);
    outportb(port+2, 3);
    outportb(port+2, 2);
    outportb(port+2, 3);
}

writ_comm(unsigned char b)
{
    outportb(port, b);
    outportb(port+2, 1);
    outportb(port+2, 0);
    outportb(port+2, 1);
}

load_leds()
{
    int order[30]={6,5,4,3,2,1,0,7,17,16,15,14,13,12,11,10,9,8,18,19,20,21,22,23,24,25,26,27,28,29};
    int ledno;
    outportb(port+2, 3);
    for(ledno=0; ledno<30; ledno++)
    {
        if (lampstate[order[ledno]]==1)
            outportb(port, 1);
        else
            outportb(port, 0);
        outportb(port+2, 3);
        outportb(port+2, 7);
        outportb(port+2, 3);
    }
    outportb(port+2, 1);
    outportb(port+2, 3);
}

```